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A MEMOIR

ON

BRITISH RESOURCES

OF

SANDS AND ROCKS USED IN GLASS-MAKING,

WITH

NOTES ON CERTAIN CRUSHED ROCKS AND REFRACTORY MATERIALS.

BY

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WITH CHEMICAL ANALYSES BY

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PREFACE TO ORIGINAL MEMOIR

RECENT study of the sands employed in the manufacture of glass has revealed the fact that the very exceptional qualities displayed by the best of them are not merely those due to chemical composition, but are the outcome of their exact mineralogical nature, and even of the size and shape of their constituent grains.

In nearly all kinds of glass there are certain permissible irregularities in both form and composition of the raw materials which allow the employment of a larger range than had hitherto been suspected. A search in localities where Glass-Sand has been worked in the past, and at other "likely" places, has shown that large supplies are available, and has given indications of directions in which further search might be profitably undertaken. The search cannot be regarded as quite exhaustive—indeed it is still being prosecuted with vigour,—but it has been thought best not to delay publication, in order to set free as soon as possible the data already collected.

This work embodies the practical results which flow from a series of investigations carried on by Dr. Boswell, with the support of the Imperial College from the beginning and of the Ministry of Munitions in its later stages. Large quantities of material have been accumulating since 1912, every locality described has been personally studied by the Author, and with the exception of certain Scottish and Irish sands received by favour of the Assistant (for Scotland) to the Director of H.M. Geological Survey, and of the Department of Agriculture for Ireland, only samples collected by himself have been subjected to analysis. The chemical analyses have been made, by kind permission of Professor Baker, in the Chemical Department of the College. They are the work of Dr. H. F. Harwood and Mr. A. A. Eldridge, who have devoted much thought and care to the methods employed. All the mechanical and microscopic analyses and other work have been

carried on in the laboratories of the Geological Department. Much assistance in indexing and in the preparation of photographs has been given by Mr. G. S. Sweeting.

Our hearty thanks are tendered to many glass-manufacturers and quarry-owners who have given the Author every facility for his work, and have freely discussed with him the technique of glass-making and the economic factors of the industry. We are also indebted for help on the chemical side, both in the discussion of results and in the indication of promising lines of enquiry, to Professor Herbert Jackson, of King's College, London, and to Dr. Walter Rosenhain, F.R.S., of the National Physical Laboratory.

As the study of sands and related sediments has become a matter of pressing national importance, and as this is the first work published on British resources of these materials, it has been thought well to go a little outside the obvious scope of the Memoir in two directions

(1) The properties of sands are so varied, and the requirements of the different industries so diverse, that the Author has entered into some detail both on the best methods of investigation and on the most convenient modes of expressing the results thus obtained

(2) At the same time, the properties of sands suitable for glass-making are in some cases identical with or allied to those useful for refractory purposes, such as steel-moulding, fettling of furnaces, and the making of silica bricks. Reference has been made in passing to properties of this nature, and the applicability of the same modes of enquiry has been indicated.

It should be stated, however, that the sands actually described in Chapter VI. are only a very small fraction of the total number examined and analysed. Hosts of others have been "turned down," either because they were wholly unsuitable or on account of the possession of properties with which the manufacturer has not so far been able to deal. As the chemistry of glass-making advances it is probable that some of these disabilities may disappear—indeed, some of them are all but overcome—and then the large amount of apparently unproductive information obtained and filed by Dr. Boswell will find its use.

W. W. WATTS,

Imperial College of Science and Technology,
November 1916.

PREFACE TO THE SUPPLEMENTARY MEMOIR.

THE reception given by those interested in glass, whether as manufacturers or investigators, to the Author's "Memoir on British Resources of Sands suitable for Glass-making," published by the Imperial College at the instance of the Ministry of Munitions of War, renders it desirable that the information accumulated up to 1916 should be supplemented by that acquired since.

Not only has search for suitable quartzose sands been followed up, but collateral enquiries have been carried out, particularly with reference to deposits bearing constituents so essential to the Glass Industry as potash and alumina. It is believed that the survey of British resources of glass-sand is now fairly exhaustive, and the Author has again made a point of visiting all the sources of supply described. A more complete account of crushed rocks and their possibilities is now furnished, together with a description of the American glass-sands in more common use.

The work for the "Memoir" received the active support of the Imperial College, the publication being approved and its cost guaranteed by the Ministry of Munitions. The supplementary work detailed in the present publication has been carried out entirely under the auspices and with the support of the Ministry, the College setting free as far as possible the services of the Author, and finding, as before, all necessary laboratory facilities in the Geological Department.

W. W. WATTS.
Imperial College of Science and Technology.
November 1917.

AUTHOR'S NOTE.

As the respective Prefaces to the Original Memoir and Supplement indicate, the greater portion of the information included in this volume has been the subject-matter of two earlier publications. It appeared imperative that such information should be put forward as it became available. But the appreciation of the earlier memoirs by those connected with the industries concerned has been such as to result in the exhaustion of the first issue and to necessitate a second edition.

In this volume the original and supplementary publications have been combined. A few portions have been re-written and further information appended, including additional analyses. Repetition has been avoided as far as possible, but the stress of the times and the need for rapid re-issue has prevented as exhaustive a scrutiny as might have been desirable. The Author therefore begs the reader's indulgence in this respect.

The Department of Optical Munitions and Glass-ware Supply of the Ministry of Munitions of War has, by its energetic and prescient measures, done much to place the Glass-making Industry of the United Kingdom on a sound basis. The scope of manufacture has been enlarged and the quality of the products much improved by the co-operation of men of business with men of pure science. The linking of scientific with industrial elements, to their mutual benefit and for the good of the Country, both under the conditions of actual warfare and of the trade-revival which will follow the War, is in no small measure due to the far-seeing policy of the Controller of this Department, A. S. Esslemont, Esq., C.B.E., who has granted every facility to the Author and freely rendered him every possible assistance.

The Author desires to record his indebtedness, in general to the Glass-manufacturers, and in particular to Professor Sir Herbert Jackson, K.B.E., F.R.S., for the help which has arisen out of many visits and discussions. Thanks are again due to Dr. H. F. Harwood

and Mr. A. A. Eldridge, of the Chemical Department of the Imperial College, who have carried out nearly a hundred complete chemical analyses and over seventy partial analyses purely for this work. About one hundred and seventy mechanical analyses and almost as many mineral analyses have also been made by the Author in connexion with the investigation. Mr W. B. Wright, B.A., F.G.S., of the Geological Survey of Ireland, kindly adds a note on some of the Irish supplies of felspar, communicated by permission of the Director. Assistance has at all times been freely rendered by Dr. W. E. S. Turner, M.Sc. and Mr. J. H. Davidson, M.Sc., of the newly-created Department of Glass Technology in the University of Sheffield. Prof. C. G. Cullis, D.Sc, of the Imperial College, has kindly read the proofs and offered many useful suggestions. The Author is also indebted to Mr. G. S. Sweeting, who has devoted much time and trouble to checking proofs, and to assisting with the photomicrographs and index.

At the time of the publication of the original "Memoir" a new organization, the Society of Glass Technology, had just been inaugurated. The valuable papers in the Journal of the Society demonstrate the need which existed for such a Body, and are indicative of the interest now being taken in scientific and technical questions relating to glass-manufacture. The work of Mr. C. J. Peddle, M.Sc., Chemist to Messrs. Wood Bros. of Barnsley, calls for special note from the geological point of view, in that he has shown the possibility of using in the Works even second-grade British sands for making the best qualities, not excepting even the optical varieties, of glass.

Finally, the Author gladly takes this opportunity of expressing his indebtedness to Professor Watts for reading the manuscript and proofs, both of this and the first edition. The work has benefited greatly by the valuable suggestions which have been the outcome of Professor Watts' success in popularizing geology by teaching and writing, and in promoting the application of geological science to industry. The plan of the original Memoir was also due in no small measure to the assistance freely and continually given by his one-time teacher of geology.

March 1918

TABLE OF CONTENTS.

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§ Sections marked thus deal with sands and rocks which are also of value for refractory purposes.

LIST OF ILLUSTRATIONS.

CHAPTER I.

INTRODUCTORY: USES OF SANDS.

Of the many mineral resources of Britain none are more abundant or more varied in quality and use than sands. Their utility, in the national economy of this country at least, has never been fully appreciated. Yet the agriculturist, the builder, the glass-maker, the metal-founder, and even the housewife, all turn in their need to the natural sand-resources of the country.

To the man in the street to-day the differences between one sand and another are neither striking nor important. This attitude has, of course, not been shared by those who are concerned with the use of sands in industry, but it is noteworthy that little or no systematic investigation of the special properties of British sands of commercial value has hitherto been attempted.

In many industries the best sand available for the purpose has been found by a lengthy process of trial and error, but the reasons for its suitability or the reverse have rarely been systematically looked into. The inevitable result is that when material of value for some specific purpose is no longer available serious delay and inconvenience are caused. Especially has this been the case in glass-manufacture and in the casting of particular steels, for which the most suitable materials in use up to the present were said to be certain foreign sands with properties peculiar to themselves. The restriction or stoppage of such imported supplies in war-time, owing to shortage of ships and labour, has set on foot enquiries as to whether suitable sands occur in Britain, and, if so, whether they can be profitably worked.

Such an enquiry necessitates not only a thorough knowledge of the sands themselves, their mode of occurrence and properties, but an investigation into the materials previously in use in each industry, and an attempt to ascertain the reasons for their special suitability. Why, for example, should one moulding-sand "burn on" to the steel poured into a mould and another yield a clean smooth casting; or one sand produce a clear, sparkling, white glass, fit for table-ware or for optical instruments, and another only a poor green bottle-glass?

All sands consist, in the main, of silica in the form of broken grains of crystalline quartz associated with various forms and proportions of impurities, partly impregnating or coating the quartz, and partly in the form of grains or dust of other ingredients. When sand is used as a source of silica, as in glass-making, the most obvious requirement is that it should be as pure as

possible and especially free from ingredients which would diminish the utility or beauty of the finished product. For other purposes, however, the "impurities" themselves may give the sand its special value. In certain industries the hardness and shape of the grains are more essential than the composition, and the difference between "angular" and "rounded" grains becomes an important matter. Again, the size of the individual grains, and more particularly the relative proportions of material of different sizes in a sample, has sometimes a bearing on the use of sand: this is spoken of as the "grading" or "grade" of the sand.

In a material used in such large quantities as sand, supplies must be cheap. This means that the sand must be abundant, loose, or at least easily disintegrated, and cheaply worked; that seams or beds must run very evenly in nature and composition, and must be cleanly marked off from other seams or materials; above all, that the market must be easily accessible and carriage inexpensive and convenient.

The term "sand" to the geologist connotes a limited range of chemical and mineral composition, and a definite grade. The term is generally extended to include other minerals than quartz, and is used in commerce for material of varying grades irrespective of composition or angularity. It is also applied to consolidated sandstones and even to hard siliceous rocks which have been crushed for commercial purposes. In this Memoir the most extended commercial application of the term will be taken.

Some Uses of Sands.

Before passing on to discuss the special properties which it is desirable for glass-sands to possess, it will be well to consider briefly how desiderata vary in different industries and applications.

Sands bearing minerals of the rare earths such as monazite, xenotime, thorianite, zircon, etc., are worked for the elements yttrium, zirconium, cerium, thorium, lanthanum, and others, which are used in the manufacture of incandescent mantles and filaments and for refractory paints. Those bearing gems, gold, platinum, cassiterite, and wolfram are similarly worked for the precious materials they contain.

Shore-sands, and others such as the East Anglian "Crags," rich in shell-fragments, form an admirable dressing for the land on account of the lime that they yield; this ingredient promotes drainage by flocculating the clay of the soil, and helps the plant by neutralizing the organic acids naturally produced. The value of such shell-sands is enhanced when they occur near to agricultural country and lime has to be imported from a distance. It is desirable that all coastal deposits should be investigated in this connexion. Even if the sands are not calcareous they render heavy clay soils lighter and more open, breaking them up by the admixture of coarser grade material, and making the land warmer, more permeable to air, gases, and water, more easily drained, and

more amenable to working. Here grade, as well as composition, is an important factor.

The "Greensands," so-called because they are coloured by the mineral glauconite which they contain in quantity, have long been used as fertilizers. The deposits of economic importance in the United Kingdom are of Cretaceous and Eocene age. Glauconite is a silicate of iron, aluminium, and potassium; it decomposes much more readily than other potash-bearing silicates such as the felspars, orthoclase and microcline, and thus liberates the valuable plant-food, potash. Some greensands are of additional value on account of their carrying calcium phosphate, an ingredient also of importance in agriculture. Glauconitic sands have also been used for softening water.

The use of sand for abrasive purposes depends on the hardness and toughness of its constituents, and on the "sharpness" of its grains. Quartz is not only hard, but, as it has no cleavage, it breaks irregularly and does not easily comminute under wear. It is employed for grinding marble and other stone, plate-glass, and metal. It is also used for arming stone-saws, and in the sand-blast applied to glass-cutting and etching, the cleaning of castings, and innumerable other industrial processes. In this work it soon loses its "sharpness" and requires frequent renewal. In the old days the housewife used a cheap, fine, sharp sand for scouring purposes, now she buys scouring-soap consisting largely of similar fine angular sand bound together with clay, soap, and gum.* "Silver-sand" is a term used for a fairly pure fine white sand, used mainly for scouring and for lightening soil. Samples sold by hardware dealers in London appear, from their mineral composition, to come from the Lower Greensand.

Large quantities of sand are now consumed in the soap-industry for the making of sodium silicate, which is a constituent of some of the commoner soaps. Not only have pure quartzites and vein-quartz been crushed to yield "sands" for abrasive and other soaps, but also the relatively impure Glacial sands of Lancashire have been pressed into service on account of their proximity to the seat of the manufacture. Sodium silicate ("water-glass") is also manufactured for preservative purposes.

In the manufacture of the artificial abrasive, carborundum (silicon carbide), sand and coke are heated together in an electric furnace. Carborundum is also used in refractory bricks, as a source of silicon in steel-making, and for certain chemical purposes where its reducing properties are of great value.

Closely allied to abrasives are friction-sands such as those used to increase the grip of wheels on metal rails. These sands must be not only hard, tough, and angular, but also dry and of even grade so as to slip freely down the feeding-funnel. Similar sands, which are better if not angular, are used in hour-glasses and

* By an order of the German Government in Aug. 1916, the use of sand instead of soap for scouring purposes was made compulsory.

egg-timers. A well-known geologist, when faced with the enquiry as to the geological age and characters possessed by these sands, gravely avoided the issue by pointing out that it was not the custom of geologists to measure time with hour-glasses!

The practice of sanding floors has almost died out, but the use of sands for road surfaces and for making road materials is increasing rapidly. Angular sands, free from clay, are utilized in the asphalt industry, the mixture of sand and pitch being of considerable value for road-dressing. The sands utilized are, as far as possible, of local origin; Lower Greensands from Surrey and Bedfordshire, and Corallian sand from Oxfordshire, have been exploited for this purpose.

Considerable quantities of sand are worked for building-purposes. Most sands are suitable for mixing with lime and water to make mortar, and usually each district is able to satisfy its own demands. (Shore-sands are, however, avoided on account of the tendency of mortar made from them to "sweat" owing to the thin films of deliquescent sea-salts having been left as a coating on the grains when the sea-water evaporates.) These salts are brought to the surface by percolating water, and left on evaporation. A similar effect is observed in the complete breaking up of Chalk fossils collected from spray-beaten cliffs, unless they have been well soaked in fresh water before storing. Building-sands should be fairly angular and not too fine, in order that their grip on the calcareous matrix may be strong, the mortar becoming truly a miniature concrete. Sands used with Portland cement ought not to be rounded in grain and should previously be washed to ensure cleanness of surface.

The clays worked for brick-making are often stiff deposits of almost pure clay. As such they can only be used for making flat tiles and pipes where great strength and adhesion are required. To reduce shrinkage and cracking during the drying and firing of bricks, sand is added to the clay and thoroughly mixed with it. A porous brick of good shape and soundness results. Here, again, the grade-composition is a leading factor. Many of the so-called clays in the geological formations of Britain are not true clays, but contain already a variable admixture of sand and are thus really loams. The Glacial brick-earths, the Keuper "Marls," and the London "Clay" are deposits of this character largely employed for brick-making.

Parting-sands, which are usually dry, sharp, fine, quartzose sands, are used in metal-casting and in the manufacture of bricks and pottery. In the case of brick- and tile-making, the sand used to "dust" the mould exercises considerable influence on the texture and colour (due usually to oxides of iron) of the surface of the article. The ability to withstand weathering and the æsthetic value thus depend in part upon the sand. The use of sand, as a substitute for flint when the latter is not procurable in the making of glaze, has not found much favour in the Potteries. Sand is used for repairing and lining kilns or "ovens" and for

dusting the floors. In metal-casting, "burnt" moulding-sand from near the surface of previously-made castings is frequently and successfully used as a parting-sand.

In connexion with water-supply, sands are of considerable importance for purposes of filtration. In order that there may be a large proportion of interspace between the grains, the sand should be fairly coarse and its grains preferably rounded, with as large as possible a percentage of grains belonging to one grade. Thus the sand should be free from clay, and of course from organic matter, while the absence of lime is an additional advantage.

Before the introduction of blotting paper sand was of service as an absorbent for superfluous writing-ink. It is said to be similarly utilized in modern industrial practice as an absorbent for explosives of the nitro-glycerine type, in substitution for such natural siliceous earths as diatomite and kieselguhr.

§ The most important commercial uses of sand, namely, those connected with the property of refractoriness to high temperatures, have been left until the last. Silica, of which quartz is the commonest crystalline form (though other allotropic modifications such as tridymite and cristobalite exist), has to be raised to a very high temperature (1650° Centigrade) before effective fusion takes place. Quartzose sands and sandstones bearing a high percentage of silica and no fluxes such as alkalies or alkaline earths are therefore in great demand for the floors, sides, and roofs of kilns and furnaces, and for the bottoms of soaking-pits. Sands of corresponding composition are also required for fettling furnaces (that is, re-coating with silica the baths which hold the molten metal), making crucibles and fire-bricks, and other similar purposes.

"Silica-bricks," used so largely for furnace-work, gas-ovens, and similar purposes where very high temperatures must be successfully withstood, are made from refractory sands. No lime or other alkaline earths, no alkalies, and very little, if any iron, should be present. Highly quartzose sands are therefore required, and a great advantage accrues if such sands possess a "bond" which is itself refractory. As examples may be quoted the kaolin-bearing whitish sands of Devon and Cornwall, associated with kaolinized granite, and the similar deposits of the Mountain Limestone district of Derbyshire and Staffordshire.

Included in the subject of refractories comes the wide and difficult problem of moulding-sands. These vary according to the metal which is being cast, the shape of the mould, and their position with respect to the metal. Thus there are facing- and core-sands in addition to ordinary moulding-sand, and the range in composition is from true sands almost entirely composed of quartz to loams containing no small proportion of clayey bond. The problem of moulding-sands is too large and controversial to be entered upon here, and demands a memoir to itself, but a few points may be

§ **Sections marked thus deal with sands and rocks which are also of value for refractory purposes.**

emphasized. Difficulties rarely arise as a result of the sand alone in the casting of iron, brass, bronze, or other alloys, where the temperature reached by the molten metal does not exceed 1250° Centigrade. No sand is, however, perfectly refractory for steel-casting, and the surfaces of the mould may have their quartz melted or recrystallized as the mineral tridymite (conversion temperature about 800° to 1350° C. according to the time occupied). To obtain a very refractory sand, high silica-percentage is demanded, and the absence of lime, magnesia, and the alkalies essential. For high-temperature castings ordinary clay must not be present, as it fuses too readily. Kaolin is a very refractory clay, but, unfortunately, it does not, like most ordinary clays, become sufficiently plastic with water to bind the sand well. A binder, either natural such as clay, or artificial, such as oil, gluten, flour, dextrin, treacle, etc., must be present in, or be added to, the sand to bind it together and ensure its standing up firmly in the required shape. At the same time the mould, and particularly the core, must be "open," that is, sufficiently permeable to permit the passage of liquids and gases when the hot metal is poured into the mould. It is therefore desirable that moulding-sand should contain a good proportion of the medium-grade sand, probably round or subangular grains being best. It should also contain a proportion of a refractory clay to act as a bond, whether or not additional binding material is to be added. The intermediate grades of fine sand and silt are of no value—in fact, they are rather detrimental. The material known to geologists as a clayey or loamy sand most nearly approaches what is required. In addition to refractoriness and suitable mechanical composition and shape of grain, moulding-sands should possess the power of taking up water to the extent of at least 4 to 5 per cent. of their own weight (some take up as much as 10 or 11 per cent.), making when moist a strong "bind." For most purposes they should not become "dead" or dehydrated quickly or entirely after casting. A quantity of fresh sand has always to be added to keep them "alive." Certain other less important conditions must also be satisfied. Reference to the grading of moulding-sands is made again later (see page 29 and Figs. 6 & 7).

The importance of obtaining suitable sands for the making of glass, and the conditions which such sands must satisfy, are considered in Chapter V. Whereas the chemical composition of a sand for many of the purposes hitherto mentioned is not the most important factor, it rises in the case of glass-making to a position of prime consequence; the mechanical composition is also of great importance, and other features, though far from negligible, sink into a minor position. Thus glass-sands are by no means the most interesting types to a geologist, the criteria being simple and for the most part easy of investigation.

For obvious reasons, the following descriptions and analyses of British sands suitable for glass-making will also be of use to those who urgently require such sands high in silica-content (and

therefore highly refractory) in other industries, for example, in the manufacture of silica-bricks, for dry-sand steel-moulding, fettling furnaces, soaking-pits, crucible-making, etc.

In the making of white bricks, pure sands low in iron-content frequently have to be transported considerable distances, when local sands bearing iron-compounds "burn up red." The sands and fuel (of which only a small supply is required) are in this case carried to the clay, but in the glass-industry, sands and other chemicals necessary for the manufacture are generally carried to the fuel, as is often the case with raw materials in other industries.

It is unnecessary to say more upon other uses of sands to justify the claim that the sand-resources of the country should be exhaustively investigated. In conclusion, it may be pointed out that just as "flint-glass" is not now made from flint but from sand alone, so "sand-paper" is often not made from sand but from powdered glass.

CHAPTER II.

§ The Nature of Sands.

Formation of Sands.—Sands and similar deposits are the result of the gradual breaking down of rocks. The sun's heat, frost, rain, and gravity are among the geological agencies which are chiefly engaged in this work of disintegration and attrition. Fragments of rock, in their continual movement to lower levels, are reduced in size by wear and tear, and broken up into their constituent mineral grains. Chemical, as well as mechanical, action assists in this work. The more easily decomposable minerals rot away, and the more obstinate are loosened from one another. In the decay of minerals the more soluble salts are carried off in solution, while the less soluble yield fine clayey or micaceous material which may be carried in suspension for long distances.

The disintegration of rocks thus results in the production of simple individual mineral grains varying considerably in size. This material is carried downwards towards the sea, and collected at lower levels. In transit it is winnowed by wind and washed by water. Most sands and related sediments are either deposited in water or have been washed down and assorted by water at some time in their history. The sorting is controlled by the size and weight of the grains, coarser grains and denser minerals being dropped down near to the source of supply. This sorting is never perfect, and it is not usual to find in geological strata a deposit made up entirely of material of one size. Nor even do we find, with very rare exceptions, that one grade—sand, silt, or clay—makes up the whole of a single bed. The manner of transport and deposition leads in any one deposit to a mixture of grades which may be valuable or inimical from a commercial standpoint.

A tendency generally exists for the collection in basins of deposit of material which has been brought from many different sources. Working against this tendency towards the production of rocks of mixed grades we have the selective transport and deposition due to currents of air and water. Heavier and larger fragments are dropped first, finer ones are carried farther, and the finest frequently travel long distances before the velocity of the stream is so far reduced that they come to rest. A fairly complete natural grouping therefore takes place, gravel, sand, silt and mud being found at successively greater distances from their place of origin. But this grading by water or air is not a perfect one; the manner of transport varies accordingly as the small particles

§ Sections marked thus deal with sands and rocks which are also of value for refractory purposes.

are held in suspension, rolled along the bottom, or carried forward by leaps (saltation), and the final deposition depends upon local variation of direction and velocity of the currents, eddies, etc., and upon the precipitating power of dissolved salts.

Sudden arrest of material near to its source, especially where it has been brought down by torrent-action, results in deposits consisting of about equal proportions of coarse and fine grades: they may be termed "non-graded" (see Fig 8 and page 32) Such a case is exemplified by many of the Cretaceous and Tertiary deposits around the Dartmoor and Cornish granite masses. Torrential streams of water poured down the slopes and ravines in past ages, rolling pebbles and boulders of granite and limestone, fully charged with grains of quartz, felspar, tourmaline, etc., and milky-white with china-clay from the decomposed felspar of the granite. The sudden checking of their velocity when they reached the still waters of the lakes, the larger sluggish rivers, or the lower ground, caused the bulk of the transported material to be thrown down higgledy-piggledy, all grades mixed, frequently as an alluvial fan.

On the other hand, the continual sorting of sediments along the shore by the action of waves and winds has resulted in the elimination from shore- and dune-sands of both very coarse and fine material. The clay and silt particles are carried far away by wind and water, and the coarse sand and gravel left alone; thus the percentage of medium-sized sand rises very high, and the deposit is almost perfectly graded.

Composition of Sands.—Usually each grain of sand is an individual mineral fragment contributed by the parent rocks which have undergone denudation. While sands are frequently made up of a large variety of different minerals, quartz and, to a less extent, felspar usually constitute more than nine-tenths of their bulk. The chemical composition of the constituent minerals, their proneness to decay, and the compounds resulting from their partial or complete decomposition, are all important factors when the commercial use of the sand is under consideration.

While the grading of sands and the sorting of minerals according to density are never perfect, a strong tendency exists towards simplification, which is helped by the proneness to decay of the less stable minerals. By repeated geological action, sorting again and again, very pure and well-graded sands come to be formed and it is noteworthy that all the best glass-sands occur in the later geological formations. On the other hand, the ancient Ordovician and Silurian "sands" are usually ill-sorted and very variable in composition.

As a rule, sands contain only a small proportion of the minerals known as the heavy minerals, which possess a density greater than 2·8. These, like quartz, have proved themselves sufficiently stable to withstand decomposition, and their presence is often a useful indication of the source of the sandy material. Most of the common rock-forming minerals occur in sediments in more or

less relative abundance. In ordinary sands the proportion of heavy minerals varies from 0·02 per cent., or even less, to 4 or 5 per cent. by weight (the latter quantity in sands of fine or superfine grade only).

The minerals composing sands may be divided into two groups: the allothigenous or detrital minerals, derived from older rocks, and the authigenous minerals, which were formed at the time the sands were deposited or at some later date. We are mainly concerned with the allothigenous minerals. Some of the heavy detrital minerals are fixed chemical compounds, others are molecular mixtures which vary somewhat in their composition, the colour and optical properties changing sympathetically with the chemical constitution. In the latter group are the pyroxenes (augite, etc.), amphiboles (hornblende, etc.), olivines, epidotes, etc.

The chief heavy minerals occurring in sands are the following:—

OXIDES. Anatase, brookite, rutile (TiO_2). Cassiterite (SnO_2), corundum (Al_2O_3), hematite (Fe_2O_3), limonite ($2Fe_2O_3 . 3H_2O$); magnetite (Fe_3O_4), spinel (oxides of Fe, Cr, Mg, Al, etc.); titanoferrite or ilmenite ($FeTiO_3$), wolfram ($(FeMn)WO_4$).

SILICATES. Andalusite (silicate of Al), augite (metasilicate of Al, Fe, Mg, Ca, Na, etc.); biotite (silicate of Al, H, K, Fe, Mg), enstatite ($MgSiO_3$), epidote (hydrated silicate of Ca, Al, Fe), garnet (silicate of Mg, Ca, Mn, and Fe, Cr, Al), glauconite (silicate of K, Al, Fe), hornblende (metasilicate of Al, Fe, Mg, Ca, Na, etc.); hypersthene ($(MgFe)SiO_3$), kyanite (silicate of Al), muscovite (silicate of H, K, Al), olivine (orthosilicate of Mg, Fe), sillimanite (silicate of Al); sphene ($CaTiSiO_5$), staurolite (silicate of Fe, Mg, Al); topaz (fluo-silicate of Al), tourmaline (boro-silicate of Al), zircon ($ZrSiO_4$).

Other compounds.—Apatite (calcium phosphate with calcium fluoride or chloride), calcite ($CaCO_3$); monazite (phosphate of Ce, La, etc.); pyrite (FeS_2), pyrrhotite (approximately FeS).

Where older sediments have been broken down to make new rocks, only the most obstinate detrital minerals, such as iron ores (including particularly ilmenite), rutile, zircon, tourmaline and others, survive, and the proportion by weight is low. When crystalline rocks of igneous and metamorphic origin are subjected to denudation, they yield a rich and highly varied assemblage of minerals. It is noteworthy that most of the heavy minerals occurring in sediments are of metamorphic origin; as examples may be quoted, spinels, garnets, rutile, tourmaline, staurolite, andalusite, sillimanite, sphene, epidote, muscovite, biotite, chlorite, kyanite, and amphiboles (including common hornblende, glaucophane, actinolite, etc.). Igneous rocks appear to provide an assemblage of minerals more liable to decomposition. However, those derived from an area of pneumatolysis are fairly stable, and include garnets, cassiterite, tourmaline, topaz, andalusite, etc. Minerals derived from other igneous rocks include zircon, rutile, anatase, apatite, brookite, white and dark micas, hornblende, and, less commonly, augite, together with a few others.

The mineral constitution of a sediment varies not only with the

parent rocks laid under contribution, but with its distance from the source of origin, the grade, and the conditions of deposition. Unless local concentration is produced by wind- or stream-action, or by the oscillatory effect of currents, the proportion by weight of the heavy crop will tend to decrease the farther we go afield, and the variety will be reduced as minerals prone to decay are eliminated. The exact connexion between mineral composition and grade is not yet thoroughly understood; it is undoubtedly a close one. During the process of deposition, other minerals may be formed through organic agency, among them being glauconite, calcium phosphate, limonite, secondary silica, etc.

Finally, we have those minerals (authigenous) which develop subsequently in sedimentary deposits as a result of alteration of other minerals; a few such are iron oxides, secondary silica, leucoxene, anatase, chlorite, etc.

If the heavy minerals are present in quantity in a sand they affect its chemical constitution very considerably. Alumina might be expected to be abundant in a heavy residue, and it is noteworthy that lime is usually low, the lime-bearing minerals, with the exception of some hornblende, pyroxene, epidote, etc., tending to decompose. In sands subjected repeatedly to the action of geological agencies, the latter group of silicates first disappears, then the ferro-magnesian minerals, and, finally, the aluminous silicates, when certain iron ores, zircon, rutile, and tourmaline only survive.

Coating of Sand-grains.—On the principle that, chemically, dirt is only "matter in the wrong place," the detrital minerals of a sand may be regarded as impurities when we desire to find a sand pure enough for a particular purpose such as glass-making. More important, however, are the impurities resulting from decomposition of these minerals and those introduced either during deposition of the bed or subsequently by the action of percolating water. An example of such an impurity is the iron staining in tints of red, brown, and yellow, so widely met with in rocks. Oxide of iron (as hematite, Fe_2O_3, or limonite, $2Fe_2O_3.3H_2O$), "Nature's colour-box," acts as a coating to the mineral grains and at times cements them together into a compact rock. Other minerals, such as silica itself, clay, fluorspar, barytes, calcite, dolomite, phosphates, etc., also play a cementing rôle. Certain unconsolidated sands, while apparently fairly pure and clean, have a fine dust-like coating of clay or calcareous material deposited upon the grains.

Association with Organic material.—Sometimes organic material such as plant-remains has the effect, either by acting as a reducing agent or by the production of humic acids, of clearing a sandy deposit of impurities or of rendering them more easily soluble in percolating water. Some of the purest quartz-sands known to us, remarkable on account of the freedom of the grains

from the slightest ferruginous coating, are associated with carbonaceous material (see Chapter VI.). The famous glass-sands of Fontainebleau in France, Lippe in Saxony, Hohenbocka in Prussia, and Aylesbury in England, are apposite examples. The purity of Coal-Measure Sandstones is interesting in this connexion, and the bleaching, to the depth of a few feet, of the yellow and red sands on our heath-lands is a well-known phenomenon. This question is considered in more detail on page 140.

Form of Sand-Grains.—During their progress from the disintegrated parent-rock to their final resting-place, mineral grains suffer continual abrasion. If the habit is needle-like, or the cleavage good, there is a general tendency for rapid fragmentation and disappearance. Brittleness and softness help the speedy reduction in size of grains, but when a soft mineral, such as mica, has a single perfect cleavage, it may be buoyed up and travel a long way.

The continual battering to which grains carried by water are subjected results in the wearing down of the sharp edges and angles, and the sands become subangular. Prolonged rolling action produced by currents up and down a shore-line, or repeated action on the same grains through successive geological cycles, may gradually round even quartz sand. Pot-hole water-action in a confined space (*e. g.* under glacier-ice) produces sometimes a beautifully rounded sand. Much more rapidly, however, are sands rounded by the action of wind, when the grains are continually rubbed against one another, or meet other obstacles, with no water present to act as a cushion or a lubricant to reduce friction. Many desert-sands consist of grains which have been rounded in this way, but just as the want of rounding does not imply the absence of desert-conditions, so also its presence may not necessarily be due to wind-action. Sand-dunes, so common around the shores of the British Isles, consist of shore-sands which have been blown up into mounds by wind-action, but that action has usually not been sufficiently prolonged to change the angular or subangular shape of the grains.

Size of Grains.—The sorting effect of water and air upon sediments has been briefly referred to early in this chapter. It is necessary to consider systematically the sizes of the grains constituting sediments and their relative proportions by weight. At the outset it should be repeated that the term "sand" has different significations to the layman and to the geologist. In the above remarks "sand" has been used in its wider commercial sense, and therefore includes related loose deposits bearing some amount of clay and other material in their composition. In its stricter geological use sand is a "grade" term, that is, one depending only upon the size of the constituent grains. Although most sands happen to be made up largely of one mineral—quartz,—the real criterion upon which the geologist bases his definition is the high percentage of grains with average diameter between 1 mm.

and 0·1 mm. (about 0·04 and 0·004 of an inch). Very coarse sands may have grains up to 2 mm. diameter, and very fine ones down to 0·05 mm., but these are extreme limits. Pebbles of diameter over 2 mm. fall into the grade known geologically as "gravel" (not the commercial term of the building trades, which connotes a coarse concrete-making bouldery deposit with a good deal of sand and fine clayey "bind"). Particles of diameter less than 0·05 mm. constitute "silts." A further limit exists, and deposits made up of mineral fragments the diameter of which is less than 0·01 mm. (0·0004 in.) are true "clays" or "muds."

A useful classification of the size-limits or grades is therefore :—

G.	Greater than 2 mm. diam.		Gravel (G).	
VCS.	,, ,, 1 mm.	,, and less than 2 mm	Very coarse sand.	Sand-grade (S).
CS.	,, ,, 0·5 mm.	,, ,, ,, ,, 1 mm	Coarse sand.	
MS.	,, ,, 0·25 mm	,, ,, ,, ,, 0·5 mm.	Medium sand.	
FS.	,, ,, 0·1 mm.	,, ,, ,, ,, 0·25 mm	Fine sand	
s.	,, ,, 0·05 mm.	,, ,, ,, ,, 0·1 mm.	Superfine sand or coarse silt.	Silt grade (s).
	,, ,, 0·01 mm.	,, ,, ,, ,, 0·05 mm.	Silt.	
c	Less than 0·01 mm.		Clay or mud grade (c).	

The letters G, S, s, c, etc., denoting the various grades are for use in this Memoir only as a means of shortening the expression of the mechanical analyses quoted in later chapters. Thus, a sand from the Red Crag at Foxhall, Suffolk, consisting of 11·8 per cent. by weight of very coarse sand-grade (>1 mm. & <2 mm. diam.), 44·1 per cent. of coarse sand-grade ($>0·5$ & <1 mm.), 41·5 per cent. of medium sand-grade ($>0·25$ & $<0·5$), 2·2 per cent. of fine sand-grade ($>0·1$ & $<0·25$), 0·2 per cent. of silt-grade ($>0·01$ & $<0·1$), and 0·2 per cent. of clay-grade ($<0·01$) would be represented thus :—

$$\frac{\text{VCS}}{11·8} \quad \frac{\text{CS}}{44·1} \quad \frac{\text{MS}}{41·5} \quad \frac{\text{FS}}{2·2} \quad \frac{\text{s}}{0·2} \quad \frac{\text{c}}{0·2} \quad \frac{\text{S}}{99·6}$$

where S represents the total sand-grade ($>0·1$ mm. diameter).

CHAPTER III.

§ Methods of Study of Sands.

For the proper knowledge of sediments, considering both their geological interest and economic value, it is desirable that we should be acquainted with the chemical, mineralogical, and mechanical compositions of each sample. In the reading of "the riddle of the sands," each of these three analyses yields interesting and valuable data, and for glass-sands in particular the chemical and mechanical analyses are most important. Although desirable, it is not so essential for commercial purposes that we should also be acquainted with the mineral composition, the knowledge is, nevertheless, of considerable value in special cases and may give an indication of the particular treatment required and of the presence of minerals detrimental to the industry, or may enable the user to ensure that successive consignments of sand come from the same quarry or bed.

Chemical Analysis.

Since quartz and felspar usually make up the bulk of a sand, and aluminous silicates that of a clay, the silica-percentage generally runs fairly high, reaching in very pure sands and sandstones 98 or 99 per cent. Complete analyses are very desirable, especially of moulding "sands," but where only fairly pure sands are investigated, as in connexion with glass-making, it is often sufficient to estimate silica, iron oxide (as Fe_2O_3), alumina, and water. Other elements will rarely be present in quantities larger than "a trace." If they should be, however, it is highly desirable that even small percentages should be recorded. Their effect in the actual making of the glass is not known, but numerous problems and difficulties have arisen in the processes and have not yet been explained. Small quantities of foreign substances may play a greater part than has hitherto been suspected in determining the character of satisfactory or unsatisfactory glass.

The chemical composition varies according to the amount and character of the cementing material upon the individual grains, but more according to the variety and relative abundance of detrital minerals present. As previously remarked, the heavy detrital minerals are mostly oxides and silicates, but borates, fluorides, phosphates, chlorides, etc., also occur. The total silica estimated in a sand is therefore made up of free silica, that of the quartz-grains themselves, together with the combined silica of the other minerals. If it is not desired to carry out a complete chemical analysis involving fusion with alkaline carbonates, the iron-content of the sand may be estimated for glass-purposes after

digesting the sand with hydrofluoric and sulphuric acids in a platinum basin, as mentioned below.

In carrying out chemical analyses of glass-sands the following precautions should be observed. Silica should be estimated in the usual way, being separated by three evaporations with hydrochloric acid with intervening filtrations. The purity of the weighed silica must in all cases be checked by evaporation with pure hydrofluoric acid and a drop of sulphuric acid; if this precaution be omitted the results obtained will invariably be slightly higher than the true value.

Iron is best determined by a colorimetric method in a separate sample after solution in hydrofluoric and sulphuric acids. As in some cases iron-bearing minerals which are only incompletely attacked by these acids are present, any insoluble residue, especially if dark coloured, should be filtered off, ignited, and fused with a little sodium carbonate or potassium pyrosulphate. The melt is dissolved in dilute sulphuric acid and added to the main portion. A blank test with the reagents alone should always be made to ascertain whether these are free from traces of iron.

Titanium may be conveniently estimated colorimetrically in the portion used for the determination of the iron. Care must, however, be taken to ensure the complete expulsion of the hydrofluoric acid, as even small amounts of this render the colorimetric estimation inaccurate.

No constituents should be estimated by difference, and the ordinary commercial chemical analyses of sands (which usually give a total of exactly 100 per cent.) are of little value for glass-making or refractory purposes.

Mineral Analysis.

Apart from the determination of the actual species present, the mineral analysis is useful as giving an indication of the relative amount of heavy detrital minerals and the quantity of such lighter minerals as quartz and felspar. The earliest method in use for the purpose of conducting a mineral analysis was that of "panning," so well known to the miner. Gentle agitation of the sand beneath water, combined with a slight rotary movement with a jerking "throw," has the effect of causing the heavier minerals to segregate at the bottom. The lighter constituents above, making the bulk of the sand, are washed off carefully in a gentle water-current. Separation of minerals such as quartz from gold or cassiterite (tin ore), each of which differs considerably from it in density, proves very successful, but for geological investigation, where it is desired to separate minerals of density a little below and a little above 2·8, the method by itself is not suitable. To reduce the bulk of the sediment, and to increase the relative proportion of heavy constituents in order to obtain a larger quantity for qualitative examination, panning is adopted. If carried too far, some of the less dense of the heavy minerals may be washed away with the lighter.

Before being analysed mineralogically, a sediment is sifted free from larger compound grains, and, if necessary, washed clean from clayey matter. The dried sand or silt is then treated with heavy liquids to obtain the small crop of minerals the density of which is greater than 2·8. The proportion of these is usually so small that examination of the untreated sand only reveals occasional grains. The densities of quartz and felspar, which make up the bulk of sands, vary from 2·54 to 2·76, while those of the more interesting detrital minerals mentioned vary from 2·9 to 4 or more. Quartz, felspars, and certain other light minerals therefore float in a liquid of density 2·8, while the heavy minerals sink. The apparatus required for mineral analysis is very simple. An ordinary funnel (dropping funnels have been used, but the open conical form is perhaps preferable) fitted with a ground-glass tap or rubber-tubing and pinch-clip is all that is required (Figs. 1 *a*, 1 *b*).

Fig. 1 *a*.

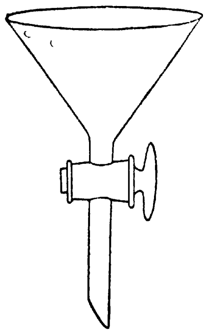
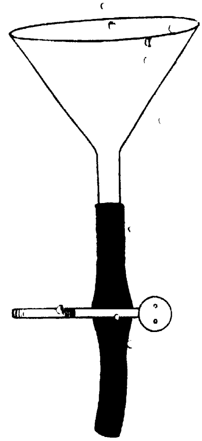


Fig. 1 *b*.



Funnels for separating heavy minerals from sands.

The most suitable heavy liquids in use are bromoform (density about 2·84) and Thoulet's (Sonstadt's) solution (mercury potassium iodide in aqueous solution, density from 2·8 to 3·1, according to concentration). The heavy liquid is poured into the funnel and the sediment added, the whole being well stirred at intervals to permit of the easier settling of the heavy grains. When the separation is complete (in practice it is probably never perfectly so), the light grains form a belt at the top of the liquid, there is usually an intervening clear portion, and a sediment of heavy grains occurs below. The latter portion of the sand is tapped off,

filtered from heavy liquid, and washed with benzene if bromoform ha been employed, or distilled water if use has been made of Thoulet' solution. The light crop is similarly dealt with, the washings i each case being saved and concentrated later over a water-bath o by distillation. Heavy liquids are thus used many times over.

If necessary, the heavy crop may be further separated for diag nostic purposes by magnetic, electromagnetic, electrostatic, rolling and other methods, and by treatment with heavier liquids, such a methylene iodide (density 3·3) *.

After some practice, many of the tiny heavy mineral grains ma be recognized by examination with a high-power hand-lens (× 1 or 20 diameters). For permanent use under the microscope the are mounted in the usual manner in Canada balsam (refractiv index about 1·53), and examined in transmitted and reflected light For rapid temporary examination it is useful to immerse some o the residue in such a medium as clove oil (refractive index abou 1·53), but then the mount is not permanent. The minerals ar identified by their shape, crystalline form, cleavage, fracture, en closures, alteration, and such optical properties as colour, refractiv index, pleochroism, birefringence, extinction-angle, interferenc figure (directions-image), twinning, etc. For these minera characters reference must be made to any good book on rock-forming minerals. The size of the different mineral grains is measured b means of eyepiece and stage micrometers.

The heavy detrital minerals usually stand out in relief (owing to their higher refractive indices) when examined in balsam o clove oil (see Plate II. figs. 2, 3, and 4). It is also useful t examine some of the lighter crop in the same way. Since quart and felspar have refractive indices very near to that of the medium (clove oil or Canada balsam), the grains if fresh and clean hav very faint borders in ordinary light (see Plate II. fig. 1). A ver slight ferruginous coating on the grains is then easily detected. Grains of a highly pure glass-sand immersed in clove oil almost disappear. Felspar is usually turbid with alteration products consisting of micaceous material or clay (kaolinization).

In certain exceptional cases, where the grading has been well carried out by natural agencies and a good proportion of heavy minerals is present, ordinary sifting will separate, to a remarkable degree, the coarser light minerals and the finer heavy ones which required the same strength of wind- or water-current to transport them. As an example may be quoted the dune-sand from Balgownie Links, near Aberdeen. A mechanical analysis of this deposit yields: Coarse sand 2·0 per cent., medium sand 91·2 per cent., fine sand 3·3 per cent., superfine sand or silt 2·9 per cent., dust, etc., 0·6 per cent.; total sand-grade (>0·1 mm. diameter) 96·5 per cent. The portion of diameter greater than 0·25 mm.

* T. Crook, "The Systematic Examination of Loose Detrital Sediments," Appendix to Hatch & Rastall, 'Sedimentary Rocks,' London, 1913. Weinschenk (translated by Clark), "Petrographic Methods," New York, 1912, and other works.

(medium and coarse sand) consists of quartz and felspar, while that of diameter 0·25 to 0·1 mm. (fine sand) consists almost entirely of heavy detrital mineral grains, epidote, augite, garnets, tourmaline, and zircon being conspicuous.

In very pure sands or sandstones, the heavy crop may be less than 0·01 per cent. in weight, but it sometimes increases to 4 or 5 per cent., as, for example, in some samples of Bagshot Sands, Inferior Oolite Sands, and others. Usually it is found that the coarser the sand becomes the smaller is the heavy crop yielded; silts and fine sands often carry the highest proportion. Estimation of the heavy crop of true clays is very difficult to make, as it has not been possible to obtain a good separation in a heavy liquid of the very fine material which takes a long time to settle.

Complete mineral analysis may, as a rule, be carried out within an hour, that time serving also for the identification of all the important detrital minerals. Mineral analysis is much more rapid than chemical analysis, and yields general information as to the chemical compounds present and their relative abundance. A check upon the chemical analysis and a knowledge of what elements to look for are thus obtained. Chemical, mineral, and mechanical analyses may all be in operation at the same time.

Mechanical Analysis.

A mechanical analysis of a sediment seeks to record the various sizes of the constituent grains, and the relative proportion by weight of grains between certain limits of size. These size-limits are known as "grades," and a useful classification has been given in Chapter II. on page 13.

The general importance of mechanical analyses in industry is only being realized very slowly. Agriculturists have long recognized the value of mechanical soil-analysis; indeed, the methods of work were first introduced in this connexion. Mining-engineers subject their battery-pulps to such analysis in order to determine the efficiency of their machinery, and they use various forms of apparatus designed to separate pulps into grades *. Water-engineers have recognized the importance of the knowledge of relative proportions of certain sizes in coarser sands and gravels in the matter of water-filtration, and the distribution and movement of underground waters †. The significance of the method has been realized to some extent in pottery-work. Not yet, however, have glass-manufacturers, metal-founders, brick-makers, and others fully appreciated the value and importance to themselves of a knowledge of the mechanical constitution of the clays, silts, loams, and sands which form their raw materials. Frequently there has been some realization of the value of the investigation, but crude methods of sifting

* H. Stadler, "Grading Analyses by Elutriation," Trans. Inst. Mining & Metall. xxii. (1912–1913) page 686.

† C. S. Slichter, "Motions of Underground Waters." Water-Supply and Irrigation Papers, U.S. Geol. Survey, No. 67 (1902); King, U.S. G. S. 19th Annual Report, 1897–8, page 67.

are often deemed sufficient. That the old order of things is changing is evidenced by the fact that elutriation apparatus has been set up in a few works as well as in a few scientific institutions in this country. Some managers of glass-works have recognized that the grade-analysis of a glass-sand is of as much importance as the chemical composition (provided, of course, that the latter does not fall outside certain limits). Otherwise no scientific investigation as to a suitable mechanical composition has been made, experience being trusted to as a general rule. Usually only sifting through wire-screens has been adopted by sand-merchants or manufacturers and founders.

(a) *Screening.*—Sifting or screening may be resorted to for coarse sands, but for fine material the procedure is objectionable both because of liability to contamination and want of accuracy. Moreover, very fine grades cannot be separated by sieves, as the apertures cannot be made sufficiently small. From a scientific standpoint the sifting of sediments through wire-screens with square or rectangular mesh does not give accurate results, since grains of various diameters up to the length of the diagonal of the aperture pass through. It is the mean and not the major diameter of the grains which determines what shall pass the screen. Sifting, therefore, does not guarantee sizing. Where sifting is adopted, round-holed sieves, with the holes punched out and set in 60° triangular spacing, should be used. It is even then questionable whether sifting much below 0·5 mm. (about 0·02 inch) is entirely satisfactory. Smaller holes than 0·5 mm. cannot be punched without difficulty, and 0·25 mm. (0·01 inch about) sieves are therefore wire screens *. The latter mesh is the minimum limit of screening adopted by the writer. In these screens and in the smaller "120 to the inch," supplied by makers, the apertures are square and tend to become clogged by use. Contamination thus occurs, especially if the metal of the screens be iron, which inevitably rusts in time. All sieves for scientific work should be made of copper or brass.

Before passing on to a description of the forms of apparatus used in elutriation, a note is desirable upon the standardization of grade-measurements. As in other scientific work, the use of the metric system units is preferable and simplifies all calculations. The grade-sizes adopted in this Memoir are therefore expressed in millimetres, and may be converted to English units if required (25·4 mm. = 1 inch). Screens are frequently made according to English units, 30, 60, 90, etc., meshes to the inch. In the I.M.M. mesh screens (inch-units) the thickness of the wires is equal to the diameter of the aperture, hence, for example, a 120-mesh screen has apertures about 0·004 inch in diameter (about 0·1 mm.). In other screens (30, 60, 90 mesh, etc.) this is not the case, the wires

* Perforated brass or copper screens are now supplied down to 0·1 mm. by Messrs. J. & F. Pool, Ltd., Hayle, Cornwall.

being of smaller diameter than the apertures. Accurate grading cannot then be carried out.

A plea must be made for uniformity in the expression of grade-sizes, preferably in millimetres. The brass screens in use in this country for soil-analysis and other grading work, while often made according to metric units (frequently in Germany) are in nests of 2 mm., 1 mm., 0·5 mm., and 0·25 mm. diameter holes, the last being square wire-mesh, and the others punched round holes. In some of the literature on mechanical analysis of sands, the last mesh-size or elutriation-size is taken at 0·2 mm. diameter instead of 0·25 mm. It is then difficult to institute comparison between analyses. The size 0·25 mm. diameter is adopted here, on account of the exigencies of the apparatus used.

(b) *Elutriation.*—For determining smaller grades of sand, screening should give place to elutriation. The process of elutriation is a classification of particles according to size by means of upward currents of water. The final velocities attained by small grains of a particular mineral of known size, when they are allowed to settle freely in water, have been determined both by calculation and experiment. The results have proved to be remarkably concordant and indicate that the controlling factor in the settling of small particles is surface-area, and not density. The free settling of particles in a liquid is due to gravity, but the velocity attained is controlled by the viscosity of the liquid. The settling of grains of diameter up to about 0·2 mm. thus conforms to a law which has been termed* "the law of viscous resistance." The velocity varies as the square of the diameter of the particle. The settling of grains above about 0·2 mm. diameter is controlled by another law, that of "eddying resistance," where the velocity varies as the square-root of the diameter. Elutriation, however, is concerned only with separation of grains up to about 0·25 mm. diameter; above that size, sifting is usually adopted. In elutriation the assumption is made, and has been found to be justifiable, that the final velocity of any grain of known size is approximately that of the upward current of water which will just keep the grain in suspension. The process enables us to classify sediments into grades, if desired, down to a limit of 0·005 mm. (about 0·0002 inch) diameter.

The velocities of water-currents required for separating suitable grade-sizes are as follows:—

0·4	mm. diameter,	47	mm per second.
0·3	,, ,,	32	,, ,,
0·25	,, ,,	25	,, ,,
0·2	,, ,,	20	,, ,,
0·1	,, ,,	6·7	,, ,,
0·05	,, ,,	1·78	,, ,,
0·01	,, ,,	0·12	,, ,,

(Temperature 15° C.)

* Sir G. G. Stokes deduced the law on purely theoretical considerations. Richards, 'Text-book of Ore-Dressing,' New York, 1909, p. 264.

The viscosity of water decreases rapidly with rise of temperature. The grading of sands is controlled by this viscosity, and cold water will therefore carry off larger grains than warm water for any one head and jet in elutriation. Care must be taken always to elutriate at approximately the same temperature. The difference in temperature of tap-water in summer and winter is sufficient to alter appreciably the results obtained in grading a fairly coarse sand.

The two chief forms of elutriators used by the writer in the investigation of sediments are the Crook pattern and a modification by Stadler of the Schoene type. The former apparatus *, designed by Mr. T. Crook of the Imperial Institute, is simpler to make and work and enables a mechanical analysis to be made more rapidly than the Schoene, many grades being separated at once. The apparatus will be best understood from the sketches. The Crook elutriator consists (Fig. 2, page 22, & Plate I. fig. 1) essentially of two cylinders, a lower narrow one A and an upper broad one B. In order to obtain a constant rate of flow upwards for the water in these cylinders a small movable reservoir C is used, with an overflow funnel and tube D. The reservoir C can be moved up and down, and a constant head and pressure of water may be obtained in the apparatus when these vary in the water-taps of the laboratory. The vessel B is fitted with a double-holed stopper through which passes a straight tube E acting as a manometer, and a bent tube F with a jet at the end. The velocity of the upward current of water in A and B is regulated by the size of the jet-opening, and the height of the water-level in C, which may be moved up and down; the velocity is indicated by the height to which the water rises in E. For separation of the sediment into sand-, silt-, and clay-grades (1 mm. to 0·1 mm., 0·1 mm. to 0·01 mm., and less than 0·01 mm. diameter) the internal areas of cross-section of the cylindrical parts of A and B must be closely in the ratio of 1 to 50. Convenient sizes are found to be 1·4 cm. diameter for A, and 9·8 cm. diameter for B, in which case to obtain the required upward velocities of the water, of nearly 7 mm. per second in A, and 0·15 mm. per second in B, the jet F is found to be about 1 mm. diameter, and must permit an outflow of nearly 100 c.c. in 90 seconds. The outflow is controlled and varied by movement of C, and when the correct measure is found, the height of the water-column in E is marked and should be kept constant. The tube A should be about 30 cm. long with a slight constriction in the drawn-out bottom end (which may also be roughened) to facilitate the grip of the rubber tube upon it. The vessel B is about 14 cm. long in the conical part and 12 cm. long in the cylindrical part. The lower portion of B and the tube A should be of the same diameter and joined by rubber tubing of the same internal diameter fitted with a clip. Another clip is used to cut

* T. Crook, Appendix to Hatch & Rastall, 'Sedimentary Rocks,' London, 1913, p. 349. Apparatus made by Messrs. A. Gallenkamp & Co. Ltd., Finsbury Square, London, J. Moncrieff, Ltd., Perth and Muller, Orme & Co., 148 High Holborn, London.

off A from C. Other details will commend themselves to the user of the apparatus. A weighed quantity of sediment (10 or 20 grammes) sifted to 1 mm., after being suitably treated if clay is present (boiled with water and deflocculated by the addition of pyrogallol or such an alkali as ammonia or washing-soda) is introduced into B. When the clips are released, the upward currents of water separate the material into grades, the sand-grade from 1 mm. to

Fig. 2.—*Crook's Elutriator.*

A. Lower cylinder for sand-grade.

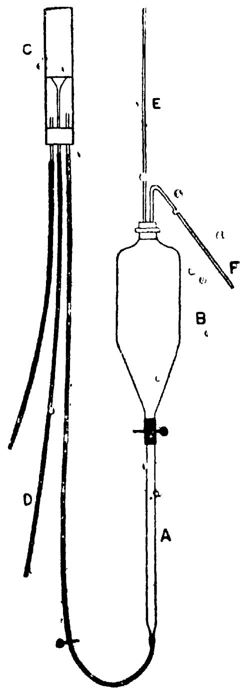
B. Cylinder for silt-grade.

C. Movable reservoir giving head of water.

D. Overflow tube.

E. Pressure-gauge.

F. Outlet tube and jet.



0·1 mm. diameter being buoyed up in A, the silt-grade from 0·1 to 0·01 mm. diameter being held in suspension in B, and the clay-grade being carried over by the water through F. The last grade may be collected in large jars and allowed to settle. The water may then be decanted off, and the sediment dried and weighed. As it is sometimes necessary, with clayey deposits, to keep the apparatus going for 12 or more hours, until the separation is complete (shown by clear water passing over from B), a very large bulk

of water accumulates, and settlement takes much time; moreover, the fine clayey material is difficult to deal with. When separation appears to be complete, the screw-clip between A and B should be closed a little for a short time before the grades in A and B are finally clipped off from one another. It is the usual practice, after drying and weighing the separated grades in A and B, to find the grade of < ·01 mm. diameter by difference. The proportion of material of diameter > 1 mm. may be found by sifting before elutriation. The grading obtained by this apparatus is therefore > 1 mm., > 0·1 and < 1 mm., > 0·01 and < 0·1 mm., and < 0·01 mm. As it is often desirable to know the percentages of fine, medium, and coarse sand, the dried portion of diameter > 0·1 and < 1 mm. may be subjected to sifting through 0·5 and 0·25 mm. sieves.

In the case of true sands, very little material should be found in B or pass over through F. The height to which a known weight of sand is borne up in A during the experiment gives the observer an idea of the proportion of the coarse, medium, or fine sand-grades. For example, in the elutriation of Fontainebleau sand, a seething mass of grains 10 cm. high, with a sharp upper limit and almost clear column of water above, is seen in A. The sharp upper limit indicates a high percentage of one grade such as coarse sand, medium sand, etc. An indefinite, hazy border, or the complete occupation of A denotes a mixture of grades, and the sand is therefore not of the best for glass-making. Crushed rocks invariably give the latter result.

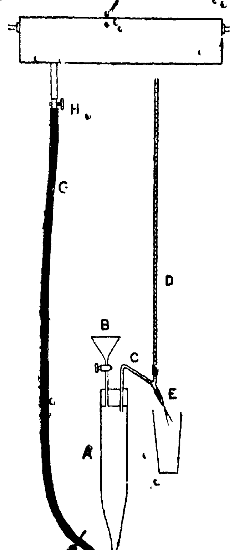
The great feature of Crook's apparatus is its simplicity and rapidity of working. By adjustment other grades than those > 1 mm., > 0·1 mm. and < 1 mm., > 0·01 and < 0·1 mm., and < 0·01 mm. can be separated. The Schoene apparatus (or its modification here described) enables grades between any desired sizes to be separated, as many as eight or nine grades being obtained if desired. The apparatus requires much more attention, and, since the grades are separated one at a time, a complete analysis of a sediment may take a considerable time (sometimes a week of working days).

The Stadler modification of the Schoene apparatus * is represented simply in Fig. 3, page 24, and Plate I. fig. 2. Essentially it consists of a cylindrical vessel A about 40 cm. long and 5 cm. in diameter drawn out and bent round at the bottom, and fitted at the top with a stoppered funnel B, and outlet tube C. The tube C divides into the vertical piezometer tube D which registers the pressure and therefore the velocity of water passing through A, and a jet E. The tank F gives a fixed head of water; the latter passes down the tube G, controlled by a stop-cock H, into A. A short length of glass tubing and a clip are attached to the

* H. Stadler, *loc. cit.* p. 689. Made by Messrs. Griffin & Co., Kingsway, London. Mr. T. Crook suggested a modification of the Schoene apparatus, using jets of varying size, in Roy. Dublin Soc., Econ. Proc. vol. i. pt. 5 (1904) p. 267. On elutriators generally, see Keilhack: 'Lehrbuch der praktischen Geologie,' 1908, 2nd ed., Stuttgart, and Ries: 'Clays, their Occurrence, Properties, and Uses,' 1908, 2nd ed., New York.

lower end of A, which may be fitted with a glass stop-cock. The tube D is about 100 cm. long and is suitably graduated. A series of jets (best made by the operator and standardized with the instrument) with holes from 2 mm. diameter down to an extremely small size (about 0·25 mm.) are fitted in turn at E. Knowing the internal diameter of A, and measuring the volume of water outflowing per second from each jet, we can plot curves and draw up a table showing the jet used and the piezometer reading for all the velocities of water in A we require.

Fig. 3.—*Stadler's modification of the Schoene Elutriator.*



A. Elutriating cylinder.

B. Intake funnel for sediment.

C. Outlet tube.

D. Piezometer.

E. Variable jet.

F. Tank to provide fixed head of water.

G. Connecting tube for water-supply.

H. Screw-tap.

A weighed quantity of sediment, previously treated as described, is washed down through B into A, and separated into grades commencing with the finest, by attaching the proper jet E and suitably adjusting the water-level in D by means of the screw-tap H. To distribute the water-current entering A, shot or mercury may be placed at the bottom. The grades are thus separated one at a time and the procedure is slow, so slow, indeed, as to give time for complete settlement of the finest grades as they come over, and permit decantation and estimation. The grades to be separated will depend on the nature of the investigation. Mr. H. Stadler, while at the Royal School of Mines, classified battery-pulps in a series of grades in a reduction ratio of the weight of a grain of each grade of four to one. For glass-sands, moulding-sands, and general geological work, it is more advantageous to adhere to the classification detailed

above, but the apparatus permits the estimation of certain useful intermediate grades ($>$ 0·01 and $<$ 0·05, $>$ 0·05 and $<$ 0·1 mm., etc.).

The relative advantages and disadvantages of the two forms of apparatus cannot be discussed here, but it may be repeated that for work dealing largely with deposits which are essentially sands, Crook's apparatus, combined with careful sifting, is simpler and more rapid in its action. The wide cylinder B in Crook's elutriator may be substituted for the cylinder A in the Schoene apparatus, giving greater accuracy in the separation of the fine grades, while using the latter apparatus.

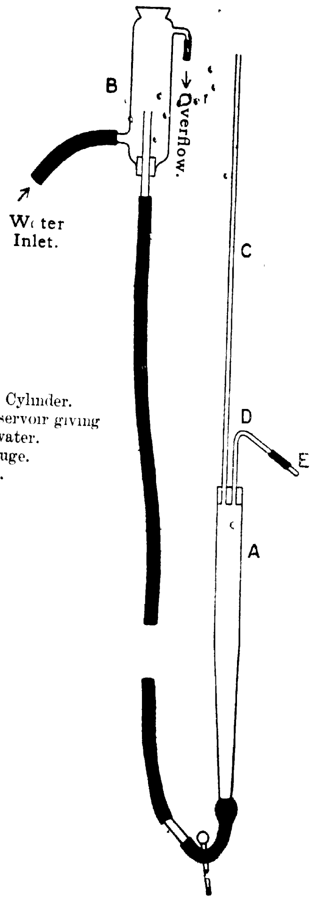
As some difficulty has arisen at the present time in getting the necessary glass-ware blown for such elutriators as that designed by Crook, it may be of service to give a brief account of the single-vessel elutriator which can be constructed from wide glass tubing usually kept in stock. Tubing one and a half, two, or three inches in diameter is eminently suitable for all but the small grades of diameter less than 0·05 mm. By changing the head of water, small differences in velocity may be obtained, but for such variation as is required for the separation of suitable grades of a sand, the size of the outlet must be varied by means of jets of differing apertures.

The single-vessel apparatus is indicated in Fig. 4 (page 26). Separation of the grades takes place in the tubular vessel A. The length of the vessel is a matter of importance, and the lower drawn-out conical portion should be equal in length to the upper cylindrical part. For two-inch tubes, each should be about 8 inches, but for the separation of grades in three-inch tubes, 6 inches for each part is sufficient. It is advisable to have the lower end of the tube opened out slightly to enable the rubber connexion tubing to obtain a grip upon it. A constant velocity for any one jet is obtained by adjusting the height of the vessel B, which gives the head of water. The vessel A is fitted with a two-holed rubber stopper, into which are inserted the manometer tube C and the outlet tube D fitted with the jet E. When the desired velocity of water passing through A is obtained for any one jet, the height of the water in C is marked. The area of cross-section of A is determined accurately, and a number of jets may be standardized to give the required velocities by measuring the outflow yielded by each. Small differences in velocity may be adjusted by raising or lowering B. Approximate sizes of jet-holes and head of water, using the two-inch and three-inch cylinders, are as follows :—

	2-inch (51 mm.) cylinder.		*3-inch (76 mm.) cylinder.*	
	mm.	mm.	mm.	mm.
Diameter of grains separated	0·4	0·2	0·1	0·05
„ „ jet-aperture	7	3	3	2
Head of water	1880	1400	700	400

As in the Schoene apparatus, described on page 23, successively coarser grades are run off, one at a time, beginning with the smallest. The Schoene apparatus differs in having a fixed head of water.

Fig. 4.—*A single-vessel Form of Elutriator.* $\times \frac{1}{6}$.



A. Elutriating Cylinder.
B. Movable reservoir giving head of water.
C. Pressure-gauge.
D. Outlet-tube.
E. Jet.
F. Spring-clip.

Usually two or three jets to each cylinder will be found to be sufficient. The jets may conveniently be made of glass-tubing, partially closed in the blow-pipe flame and blunt-nosed. Each is attached to D by rubber connexion-tubing, close up so that the

glass parts are touching. Care should be taken that if the rubber or glass-tubing connecting A and B is replaced by longer or wider material, the overflow should be remeasured and any necessary correction of head made. Friction plays a very great part in retarding the flow of water through tubes, especially when the high velocities necessary to grade to 0·3 and 0·4 mm. are obtained. The tubes connecting A and B are therefore made as wide as possible, and they should not be changed in length or diameter nor should rubber be replaced by lengths of glass, without checking all velocities again. (These remarks apply also to the Crook and Stadler elutriators.)

The accuracy of the elutriation processes has usually been checked by examination and measurement of grains from the separated grades under the microscope. A word of warning is here necessary. In data relating to mechanical analyses of sediments (for example, moulding-sands, fire-clays, etc.), the average diameter of the grains constituting each grade is given. Both geologists and mining-engineers have found that the average diameter obtained by microscopic measurement has usually too high a value. When almost spherical grains of known specific gravity from any one grade are counted and weighed, the average diameter may be found by calculation. This value is usually less than that obtained by microscopic measurement, because the grains are rarely true spheres. They tend to lie in their "flattest" position, and thus the minimum diameter is usually not measured. Particularly is this the case with certain crushed minerals, among which is quartz. Quartz, although it has no cleavage, tends to crush into a very flaky form, and elutriation products of this material, which has been recommended as a glass-sand, always appear, when examined under the microscope, to be coarser than they really are (compare, for example, figs. 2 and 5, Plate IV.).

It is an interesting fact that the average diameter of the grains of a sand is frequently a very small figure which is not at all the size of grain that appears to the eye to be representative of the sand. An example will best illustrate the point.

Taking a well-graded, washed sand, such as that from Lynn, of mechanical composition: $>0{\cdot}25$ and $<0{\cdot}5$ mm., $90{\cdot}8\ \%$; $>0{\cdot}1$ and $<0{\cdot}25$, $8{\cdot}7\ \%$; $>0{\cdot}01$ and $<0{\cdot}1$, $0{\cdot}2\ \%$; $<0{\cdot}01$, $0{\cdot}3\ \%$; we find that the true average diameter (the sum of all the diameters divided by the number of grains) is 0·0103 mm. This appears to be a very low figure, and is due to the fact that even in a tiny percentage of a small grade an immense number of grains occur. (Care must, of course, be taken before elutriating to ensure that the sand is dry, or moisture may be estimated as clay-grade by difference.) Lynn Sand was chosen as being one of the best-graded materials. The average diameter of Lippe Sand (see page 131 and Plate III.) similarly worked out at 0·009 mm. If, however, we multiply the percentage weight of each grade by the average size of that grade, add together the results and divide by the total

percentage weight (*i. e.* 100), a method adopted by H. Ries*, we obtain a result which is certainly not the average diameter, but which is a size apparently representative of the sand when examined and measured under the microscope. In the case of the Lynn Sand above, it works out at 0·285 mm. The latter result might be termed the "dominant diameter"; it has been called erroneously the average diameter. That it is not the latter may easily be seen by making a similar calculation upon a sandy clay.

In connexion with the underground passage of water through sands, Hazen desired to find the mean or average-sized grain of each sample †. This mean size he termed the *effective size*, and it was to be such that, if all the grains were of that diameter, the sand would have the same transmission capacity that it actually possessed. Hazen adopted screening, and decided that the effective size should be determined from the mesh of the sieve which allowed 10 per cent. to pass and retained 90 per cent. by weight of the sand. The variety of sizes present in a sample he indicated by the *uniformity coefficient*. To determine this, he found the size of the sand-grain such that 60 per cent. was of smaller and 40 per cent. of greater diameter. Then the uniformity coefficient $= \frac{\text{this size}}{\text{effective size}}$. Hazen found that 10 per cent. of small grains had the same effect on water-flow as 90 per cent. of the larger grains, provided that the uniformity coefficient was not greater than 5.

The uniformity coefficient for the majority of British sands here described (dominant grade = medium sand $>0·25$ and $<0·5$ mm. diameter) is nearly 2.

(c) *Graphical Expression of Results.*—The expression of mechanical analyses in the form of curves brings out contrasts and similarities in sediments more graphically than does the use of space (*e. g.* "strip" or "butterfly") diagrams. Similar graphs have been used for screening-analyses in connexion with water-supply and percolation, in the publications of the United States Geological Survey, and for analyses of moulding-sands in those of the Geological Survey of Denmark. The curves here drawn are to be regarded as approximations only, serving to visualize the lists of figures given in the tables of mechanical analyses. Reference should always be made to the latter. Cumulative percentages by weight of material above the grade-size (marked horizontally) are set off vertically as ordinates. For example, in the curve XW (Fig. 5) representing a specimen of London Clay, about 17 per cent. of the sample is of diameter greater than 0·1 mm. and about 55 per cent. of diameter between 0·1 and 0·01 mm.; the ordinate at the latter grade-size is therefore 17 + 55 = 72 per cent. The

* Trans. Amer. Foundrymen's Assoc. 1906, page 63.

† C. S. Slichter, "Motions of Underground Waters." Water-Supply and Irrigation Papers, U.S. Geol. Survey, No. 67 (1902).

horizontal scale adopted is proportional to the logarithms of the diameters quoted, in order to keep the scale representing the various grades down to clay within the compass of the page.

The curves are plotted from four or five points, with information for intermediate points obtained from microscopic examination.

Horizontality in any part of the curve means the absence of the grade-size corresponding to the distance that such horizontality extends. Verticality in the graph means a considerable percentage of the grade-size corresponding to the position of the vertical portion. In the figures for glass-sands and other similar well-graded sands the verticality is probably greater than represented, but the absence of information as to percentages of intermediate grades prevents more accurate plotting. All the curves eventually turn up at the right-hand end (in the clay-grade portion) when the total reaches, as it must do, 100 per cent. The approach to the upper line may be asymptotic, *i.e.* the particles may gradually become smaller and smaller to vanishing point; but it is more probable that in most sediments a lower limit of size of particle is reached, when the curve turns up thus —⁄. Probably solution eventually causes the disappearance of tiny particles before they disintegrate mechanically.

Representing the mechanical composition of a sediment as a curve (Fig. 5) obtained by plotting cumulative percentages of the various grades against the diameter of particles in the grades, we see that a pure gravel, 100 per cent. of diameter not less than about 2 mm., is represented by the vertical line AB, a pure sand of medium grade by CD, a pure silt by such a line as EF, and a pure clay by another vertical line such as GH beyond. Such ideal sediments do not seem to be present in nature. The curves TU, WX, and YZ represent actual British sediments which have been subjected to mechanical analysis. The curve TU is that of a true medium sand from the shore at Kynance Cove, Cornwall, WX is a true loam, worked for brick-making, from the London Clay at Ipswich, and YZ is a true clay of Upper Glacial age from Hasketon, Suffolk. These three sediments approach very nearly to the highest perfection to be expected from natural deposits. With them should be compared the curves indicated in Fig. 6, which are of some well-known and successful moulding-sands. The upper curves, representing the famous "Belgian Red" and "Cornish Red" (Pliocene Beds, St. Erth, Cornwall) moulding-sands, etc., are clearly from their position indicative of coarser sediments than the other represented, which is the well-known "Erith" sand from Charlton (Kent), much finer in grain. In spite of the variation in size of the constituent grains, the proportion of the grades is constant and causes the curves to be remarkably sympathetic. The graph of the "Belgian Red" moulding-sand is seen from the figure to cut across the others, owing to that deposit containing a greater proportion of clay, apparently ferruginous kaolin. Actually it is more nearly the ideal moulding-sand expected on theoretical grounds, *i. e.* one with high clay-grade for bind, and

Fig. 5.—*Mechanical Analyses of Sediments : Graphical representation.*

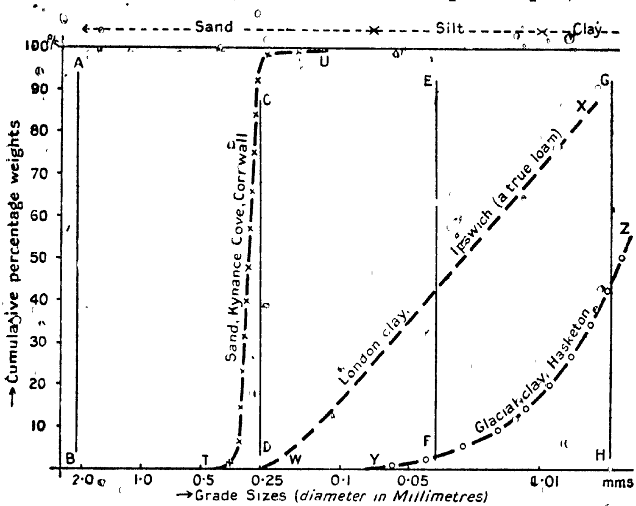


Fig. 6.—*Mechanical Analyses of Sands : Moulding- and Glass-Sands compared.*

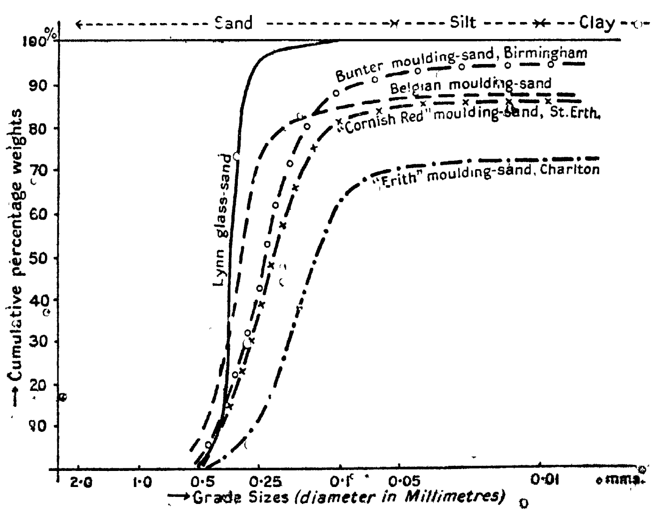


Fig. 7.—*Mechanical Analyses of Sands. An attempt towards representation of Ideal Glass- and Moulding-Sands.*

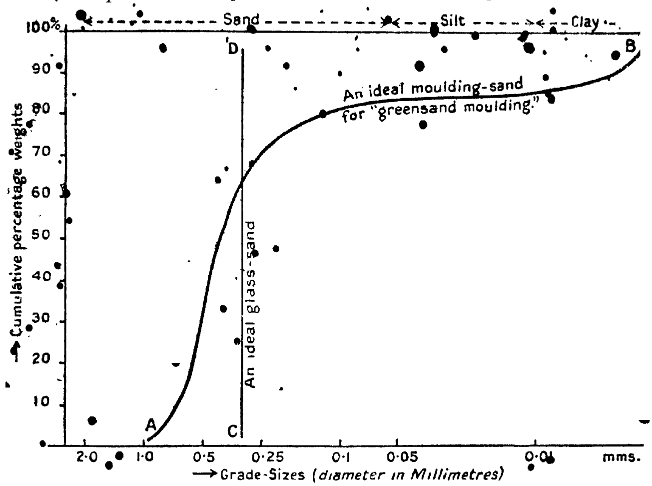
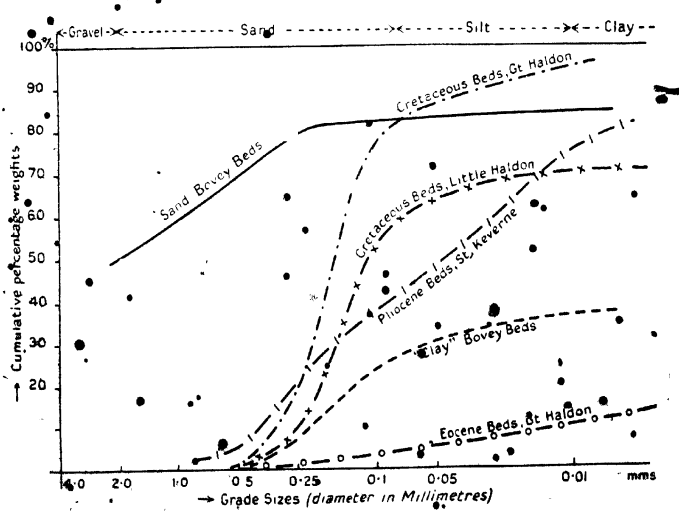
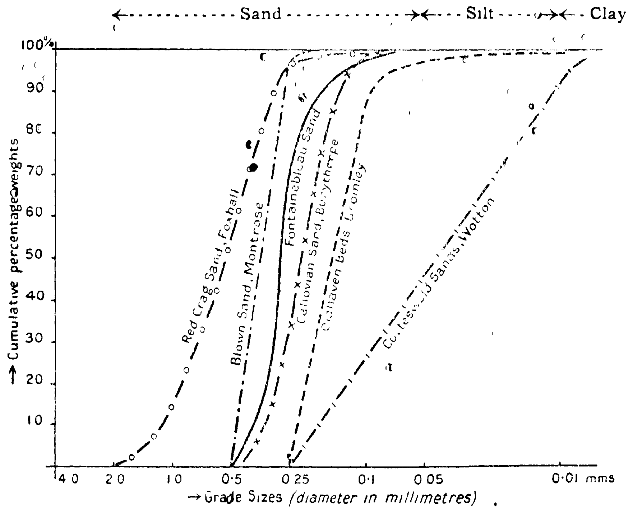


Fig. 8.—*Mechanical Analyses: Unsorted Deposits.*



with a good quantity of sand-grade (other than fine sand) for openness and ventilation. The ideal moulding-sand for "greensand moulding" would be graphed as in Fig. 7, AB, the horizontal part of the curve passing over the fine sand- and silt-grades. Some of the Pliocene, Eocene, and Cretaceous Beds fringing the kaolinized granite-masses of Devon and Cornwall approach very closely to this ideal. Moreover, the clay-grade is composed largely of kaolin, the refractory properties of which are excellent. The difficulty to be solved is that of making the kaolin, which is not a very plastic clay, into a good "bind."

Fig. 9.—*Mechanical Analyses: possible variation in true sands.*



On the other hand, a perfect glass-sand should be all of one grade, preferably among those sizes not so desirable in a moulding-sand. In other words, a sand from which glass is to be made should have all its grains of one size, not greater than 0·5 mm. or less than 0·1 mm. diameter. The curve CD (Fig. 7) would represent such a sand.

With these ideal cases should be compared those of Fig. 8, representing such unsorted deposits as those mentioned in Chapter II. The curves in Fig. 9 show the possible variations in grade of British sands, and from a comparison of Fig. 9 with Figs. 10 & 11, page 50 (see also Plate III. figs. 1–5), the special grading of sands for glass-making will be realized. The badly-graded products obtained by crushing rocks are indicated in Fig. 12, page 79 (see also Plate III. fig. 6).

CHAPTER IV.

GLASS-MANUFACTURE.

Literature on Glass-Sands, etc.—Comparatively little appears to have been written upon the important subject of glass-manufacture, and especially in this country is there a dearth of literature bearing upon the problem. Only a small amount, too, of the available literature refers to modern processes and developments. For those interested in the methods used, and those who desire to realize to what extent knowledge of our geological resources may help the trade, the following works are recommended:—

Glass Manufacture (Constable), by Walter Rosenhain, 1908.
Glass (Sir Isaac Pitman & Sons), by P. Marson. Just published.
The Principles of Glass-making (G. Bell & Sons), by Powell and Chance, 1885.
Glass. Articles in 'Encyclopædia Britannica,' 11th edition, by Harry J. Powell and W. Rosenhain.
Jena Glass (Macmillan & Co.), by Hovestadt, translated by J. D. and A. Everett.
Glass-blowing and Glass-working, by Thomas Bolas, 1898.
Abridgments of Patent Specifications of Glass · 10 volumes, 1855–1915.
Glass-blowing, by W. A. Shenstone, 1886.
Glass Article in Thorpe's Dictionary of Applied Chemistry, 1912.

Le Verre et le Cristal, by J. Henrivaux, 1897.
La Verrerie au XXme Siècle, by J. Henrivaux, 1911.

Die Glasfabrikation, 2 vols., by R. Dralle and others, 1911.
Die Glasfabrikation, by R. Gerner, 1897.
Die Herstellung grosser Glaskorper, by C. Wetzel, 1900.
Die Glasindustrie in Jena, by E. Zschimmer, 1909.
Glas. being Part I. of Chemische Technologie, by B. Muller, 1911.
Die Glasatzerei, by J. B. Miller, 1910.
Zeitgemasse Herstellung, Bearbeitung, und Verzierung des feineren Hohlglases, by R. Hohlbaum, 1910.
Die Bearbeitung des Glases auf dem Blasetisch, by W. Lermantoff.
Schmelzen und Krystallisieren, by G. Tammann.
Die feuerfesten Tone, by C. Bischof.

The following catalogues and periodicals may usefully be consulted:—

Catalogue of works on glass in the Library of the Society of Glass Technology.
Catalogue of works on glass in the Library of the English Ceramic Society.
Catalogue of works on glass in the Public Reference Libraries of Birmingham, Leeds, and Manchester, 1913.

Catalogue of works in the Patent Office Library dealing with Ceramics and Glass, 1914.
Sprechsaal Kalendar, annual volumes.
Periodicals :—
Die Glasindustrie.
Sprechsaal.
Glashütte.
Diamant.
Silikats-Zeitschrift.
Keramische Rundschau.
Tonindustrie Zeitung.
Journal of the Society of Glass Technology.
Transactions of the Optical Society.
English Ceramic Society.
American Ceramic Society.

References to other scattered papers, etc., and to additional French and German literature, will be found in the works cited above.

Lists of formulæ for various glasses have recently been issued by the Institute of Chemistry *. Others are supplied confidentially.

On the important question of glass-sands, less still has been written; indeed, the literature may almost be said to be non-existent. In very few countries do we know the properties, quantity, and workability of the sand-resources generally, and little of this knowledge concerns glass-sands.

No thorough discussion of the properties and desiderata of glass-sands is known to the writer. Scattered notes are to be found in publications of the Geological Surveys of the United States, Denmark, etc. These are referred to in their appropriate places hereafter †.

The dearth of literature upon glass-sands in this country is doubtless due to the fact that before 1914 manufacturers of glass in the United Kingdom used large quantities of foreign sands, notably from France, Belgium, and Holland. The use of such imported sands, frequently to the entire exclusion of our own resources, was due to two main causes: in the first place, the sands were generally purer than the obtainable British sands, and, in the second, the cost was less, particularly when foreign sands were brought back as ballast on a boat's return journey. The latter state of affairs arose because the British supplies of sand were frequently situated inland; thus the cost of transport by water from abroad was less than that by rail from one part of the country to another. So little has Britain investigated and relied upon her own resources of sand, that it is not surprising to find a German writer upon glass-making declaring categorically in 1885 that the English sands were iron-bearing, while only those of the Isle of Wight were considered worthy of mention. It is stated that the English obtained glass-sand from

* Proceedings, 1915, Parts ii., iii., & iv.

† Since the above was written, there has appeared a discussion of the glass-sands of the U.S.A., by Fettke, Trans. Amer. Cer. Soc. 1917, vol. 19, page 160.

France, America, and Australia!* Such statements are hardly correct; for as far back as 1858 Northampton Sands, Ashdown and Tunbridge Wells Sands, Aylesbury sands, Aylesford sands, Lynn sands, Thanet Sands, Bagshot Sands, and others were already in use †.

Tscheuschner, the German writer referred to above, mentions that glass-sands were obtained in France from Maintenon, Fontainebleau, Nemours, and Champagne; and in the German Empire from Nievelstein in the Rhine Province, Hohenbocka in Prussia, and Lemgo in Westphalia.

Raw Materials: Importance of Sand.—The various kinds of glass may be regarded as mixed silicates (and, to a smaller extent, borates) of the alkalies, sodium and potassium, the alkaline earths, calcium, barium, magnesium, etc., and lead, iron, zinc, and aluminium.

Probably the silicates, borates, and oxides are in a state of mutual solution in one another; but, just in the same way as much dispute exists among petrologists as to the combinations into which the various elements enter in a natural molten rock-magma (of which a natural glass such as obsidian is only a solidified form), so authorities on the chemistry of glass are by no means agreed upon the actual compounds formed. The geologist is mainly concerned with the fact that the finished product, glass, consists of 60 to 75 per cent. of silica, which is contributed to the raw mixture in the form of a sand.

The "batch" or mixture of raw materials such as sand, soda-ash (Na_2CO_3), salt-cake (Na_2SO_4), potash (as K_2CO_3 or KNO_3), limestone ($CaCO_3$), red lead (Pb_3O_4), manganese dioxide (MnO_2), coke or anthracite (C), alumina (Al_2O_3), boric anhydride (B_2O_3), barium carbonate, calcium fluoride, etc., according to the kind of glass required, usually consists of 52 to 65 per cent. by weight of sand. A small amount of silica is sometimes added in the form of felspar; but the percentage of silica is increased in the final product (which, when molten, is termed "metal"), as a result of the loss of such gases as SO_2, CO_2, etc. The silica-percentages in some well-known glasses are as follows:—Window 53 per cent., lead flint 53 per cent., soft soda (chemical laboratory ware, X-ray tubes, etc.) 54 to 56 per cent., green bottle 57 per cent., miners' lamps 59 per cent., combustion tubing 60 to 62 per cent., plate 62 per cent., resistance (very like Jena) 63 per cent., soda-lime (Venetian) 73·4 per cent., potash-lime (Bohemian), 71·7 per cent., and so on, the proportions varying somewhat in actual practice.

In point of bulk, therefore, the sand is the most important

* 'Handbuch der Glasfabrikation,' E. Tscheuschner (Weimar, 1885), page 72. Analyses of various glass-sands are also given in Dralle's 'Die Glasfabrikation,' and of German glass-sands in the 'Sprechsaal Kalendar' (*e. g.* 1916).

† Mineral Statistics: Mem. Geol. Survey (1860, being Part ii. for 1858), page 374.

ingredient, and its properties influence to a large extent the character of the glass obtained.

As emphasizing the bearing of the sand used upon the qualities of the glass, an example given by Hovestadt may be quoted. Thermometer-glass, made in the Thuringian Forest district, owes its special quality to certain sand found only in the neighbourhood of the village of Martinroda. The glass withstands repeated melting, blowing, and fusing without change; while ordinary glass, such as that of windows, becomes rough and dull of surface even after short exposure to the flame." Other sands are believed to be unsuitable, especially the pure sand from Brandenburg. The cause of excellence is attributed to the alumina present, which forms 3·66 per cent. (page 21, Everett's translation).

The raw materials used in glass-manufacture may be conveniently grouped, from the geologist's point of view, into two classes: (a) Rocks and minerals such as native silica (in the form of vein-quartz, sands, sandstones, or quartzites), felspar, kaolin, limestone, anthracite, fluorspar, cryolite, etc., which are used, except perhaps for washing, in the state in which they are won; and (b) Chemical products which have been prepared from naturally-occurring substances. Among the latter are salt-cake, soda-ash, borax and boric anhydride, potash, alumina, arsenic, and compounds of lead, barium, manganese, cobalt, chromium, nickel, zinc, and other metals.

The resources of silica, potash-felspar, and kaolin are referred to in the following pages. No difficulty exists in obtaining fairly pure limestone (that from Buxton in Derbyshire is most widely used) and anthracite. Cryolite is indirectly imported from Greenland and does not occur in the United Kingdom, nor is it known to occur in the British Empire; the resources of fluorspar have recently been dealt with in a publication by H.M. Geological Survey *.

Of the second group, the minerals from which potash can be obtained are mentioned hereafter. British resources of alumina have yet to be described in detail. Those of barium (as barytes and witherite) and manganese ores have been dealt with by H.M. Geological Survey †. Ores of arsenic and zinc occur in Great Britain, but the resources have not at present been systematically described. The minerals which yield boron compounds, cobalt, chromium, and nickel are imported from abroad, and are used in small quantities only.

Colour etc. of the Glass.—Upon the sand depend the transparency, brilliancy, lustre, and hardness of glass. The uniform density of glass, as will be seen in the sequel, is influenced to no small extent by the mechanical composition of the sand. In

* Special Reports on the Mineral Resources of Great Britain, vol. iv., Fluorspar; (1916).

† *Ibid.* vol. i., Tungsten and Manganese Ores; vol ii., Barytes and Witherite.

order that the finished article may have plenty of "life," and the sparkle and "water-whiteness" of the best glass, due attention must be paid to obtaining, and treating suitably, the sand itself.

For optical glass and table-ware ("crystal" and "cut-glass") only the purest sands can be used.

Where the glass is blown or rolled into thin sheets, as in the making of laboratory-ware, lamp chimneys, incandescent electric globes, window-glass, etc., the requirements are not so exacting, but the sand must still be fairly pure. The light passes through only a small thickness of glass, which, although possessing a slight colour when seen in a thick mass (sometimes a faint green due to the small quantity of iron in the sand, at others a faint pink due to manganese which has been added in the form MnO_2 as a corrective to the iron), appears colourless and has plenty of life in the attenuated state. The colour may then be observed by looking at the object "edge-on," that is, through a much greater thickness of material.

While only the merest trace of iron impurity in the sands is permitted for optical and cut-glass, less pure sands containing 0·1 per cent. of Fe_2O_3 may be used for plate- and window-glass, chemical apparatus, globes, etc.

Small quantities of iron or other impurities are sufficient to detract from the lustre of table-ware, or to spoil the power of transmitting light possessed by lenses and prisms of optical glass.

Coloured glasses are prepared in one of two ways, the more common being that of adding a chemical compound to the batch, and thus obtaining either a coloured silicate (chromium for green glass, cobalt for blue, etc.), or reduction to a very finely-divided metallic state (copper or gold for ruby glass). The other method is known as "flashing," and consists in covering the surface of colourless glass with a very thin coating of a coloured material (*e. g.*, copper or gold ruby glass, which is opaque when only $\frac{1}{16}$ inch thick). In either case, to obtain purity of colour, it is essential that no amount of impurity such as iron should be present.

The Process of Glass-making.—The manner in which the batch is melted to form the glass has also a bearing on the kind of sand used and its physical properties. Two different processes are adopted. The batch may be placed in open or closed "pots," or crucibles, which stand upon a kind of "false-bottom" in the furnace. This floor is known as the "siege" (Fr. *siège*) and has "ports" or openings in the middle (or in the end and side walls of the furnaces), by which the heated gas and air enter playing around the pots. The pots are arranged around the periphery of the furnace to facilitate the extraction of the molten "metal" from them as "gatherings" upon the glass-workers iron rods or blowing-irons. Melting of the batch from the bottom upwards is ensured as far as possible. For ordinary glass-work open pots were used; but for special ware, indeed for most purpose nowadays, impurities are kept out by using crucibles covered witl

a hood, "gatherings" being taken through a mouth-like opening at the side.

In the tank-furnace the batch is melted in a long bath or tank constructed from blocks of highly refractory siliceous sandstone. Much larger quantities of material can be dealt with in this way; for, besides the larger capacity, the process is a continuous one, the batch being fed in at one end of the furnace (filling-hole) and the metal being continuously drawn from the other, and cooler, end of the tank (working-hole). Special and best quality glasses cannot be made in this manner. The tank is not covered, and the mixture of burning gas and air, forming sheets and jets of flame, enters through ports in the side-walls above the surface of the metal.

When the fusion of the batch is complete, the metal is freed from bubbles of evolved gases and entangled air by means which vary according to the kind of glass made and the craft of the glass-maker. This procedure is known as "fining."

The pots are usually made of fire-clay (or of fire-clay mixed with other highly resistant materials), and are very carefully prepared. The floors, sides, and crowns of the furnaces are constructed from highly refractory silica-bricks and fire-bricks (*e. g.*, Dinas, Glenboig, and Stourbridge bricks, etc.), but frequently both pots and bricks are partially melted in the intense heat obtained in the furnace (1500°–1600° C.). Most furnaces are now built on the regenerative, and some on the recuperative, principle, by which the hot spent gases issuing are utilized to heat the incoming mixture of gas and air.

For the respective advantages of each kind of furnace, reference must be made either to books or glass-makers. Briefly, it may be said that for special glasses, where covering of the metal is essential, when considerable time is occupied in complete fusion and mixture of the constituents, when they must be kept together long enough to combine, and where accurate regulation is required, the pot-furnace is more suitable. When large quantities of less pure glass are required, maximum space and heating are to be utilized, and time saved by continuous working (for pot-furnaces must cool down and be reheated, and pots fail and need renewing) the tank-furnace is better. The level of the metal is kept fairly constant, and therefore convenient for the withdrawal of gatherings, in a tank-furnace; while the glass left in the bottom of a pot frequently becomes "cordy" or "wavy" on blowing, and rarely is as good, or of the same composition and properties, as that already used from the pot.

CHAPTER V.

THE REQUIREMENTS OF A GOOD GLASS-SAND.

The sand hitherto used in this country for all the best kinds of glass-work is that of Upper Oligocene age from Fontainebleau, near Paris. It is shipped from Rouen and delivered in Britain at a fairly cheap rate. Since the outbreak of war, manufacturers have found considerable difficulty in getting it through, owing to shortage of barges and labour, and the dislocation of trade. Enquiries were therefore made for suitable substitutes from the geological formations cropping out in Britain, with the results given later in this Memoir.

§ *Characters of Fontainebleau Sand.*—As a glass-sand, that of Fontainebleau nearly approaches perfection *. If, therefore, we look into its properties in some detail, we may hope to realize the desiderata of a first-class glass-sand, and know what to look for in any other deposits exploited for glass-purposes.

(a) *General Characters.*—To the unaided eye, the sand is a beautiful white, fine, even deposit. With a hand-lens the sand appears to be composed of water-clear quartz, and only here and there a few dark grains are to be seen. Unless the sand has been washed after its arrival at the works (and for all special glasses for optical purposes and table-ware it is usually washed carefully), a little dirt and occasional specks of black coaly matter may be seen. Such impurities are. of course, adventitious, and obtained from trucks and barges in course of transit. The grains have no coating of white clayey matter, as many sands have, their white appearance being due to the ordinary reflection of light from irregular surfaces They are almost invisible under the microscope when mounted in media such as clove oil, Canada balsam, etc., the refractive indices of which lie very near to that of quartz (Plate II, fig. 1). The grains are free from the pale yellowish or brownish coating of iron oxide so frequently seen in sand.

(b) *Chemical Composition.*—Chemical analyses (see Table VI.) show that the sand contains 99·65 to 99·97 per cent. of silica, and therefore must be composed almost entirely of pure quartz. Only a small quantity of iron oxide is present; hence glass made from the sand is practically water-clear (provided, of course, no colouring compounds are added). The alumina percentage is very low, being probably accounted for by the rare grain or two of felspar seen, and by the few heavy minerals present. Lime and magnesia are practically absent.

* The sand from Lippe, in Saxony, is slightly purer, but Fontainebleau sand being better known in this country, has been selected for description.

Chemical Analysis of Fontainebleau Sand.

	Derby Glass Works.	Barnsley Glass Works.
SiO_2	99·67	99·80 per cent.
Al_2O_3	0·19	0·13
Fe_2O_3	0·002	0·006
CaO	0·14	trace
MgO	none	n. d.
Loss on ignition	0·18	0·18
Totals . .	100·182	100·116 per cent.

(c) *Mineral Composition.*—Fontainebleau sand, like many other very pure quartzose sands, contains less than 0·02 per cent. of heavy minerals, which is below the average for all sands. In this heavy crop, of density $>2·8$, the minerals present are clean and fairly coarse in grain. They include

magnetite, in irregular black grains ;
zircon, in slender prismatic crystals ;
rutile, as irregular foxy-red grains ;
ilmenite, altering to leucoxene ,
tourmaline, blue and brown, in somewhat rounded prismatic fragments ;
staurolite, in golden yellow angular grains ,
andalusite, as small clear pleochroic grains ;
muscovite, in larger flakes ;
kyanite, in almost rectangular well-cleaved fragments ;
limonite, etc.

From the chemical composition of these detrital minerals it is seen that silica is present in some amount, and that small quantities of iron, aluminium, titanium, magnesium, zirconium, and boron occur. The proportion of heavy minerals in the sand is so small, however, that even with the large bulk of sand used for the batch, the aggregate amount of impurities is slight.

(d) *Mechanical Composition.*—The evenness in grain of the sand (to the eye) has been commented upon, and mechanical analyses determined in elutriators like those described in Chapter III. are :

Diams. in mm.	CS. $>0·5$ & <1.	MS. $>0·25$ & $<0·5$.	FS. $>0·1$ & $<0·25$.	s. $>0·01$ & $<0·1$.	c. $<0·01$.	S. Total sand-grade: $>0·1$ & <1 mm.
1 ..	$<0·1$ %	70·6 %	26·6 %	2·8 %	0·0 %	97·2 %
2 ..	.	70·3	28·3	0·6	0·8	98·6

1. Obtained by the kindness of Mr. Frank Wood, Managing Director of Messrs. Wood Bros., Glass Manufacturers, Barnsley.

2. Obtained by the kindness of Mr. S. N. Jenkinson, Managing Director of the Edinburgh and Leith Glass Co. Ltd., of Edinburgh.

A suitable method of graphical expression is by means of a curve, as in Figs. 9, page 32, and 10, page 50. Practically no grains

occur with diameter above 0·5 mm., and very few are below 0·1 mm. diameter (see Plate III. fig. 1).

(e) *Shape of Grains.*—Lastly, as regards shape, Fontainebleau sand is made up of grains consistently subangular. To what extent the rapid and even melting of the batch depends upon the shape of the grains of sand is a disputed question, but it is clear that such a sand as that of Fontainebleau, the grains of which are all of similar shape, is preferable to one containing a mixture of angular, subangular, and rounded fragments.

(f) *Economics.*—In addition to the recommendation afforded by chemical purity, evenness of grade, and suitability of size and shape, Fontainebleau sand can be transported cheaply and conveniently to most British glass-making districts. This is due to the insular position of Britain, and to the fact that the sand can be directly shipped from Rouen, and without further handling may be discharged high up the estuaries which notch our industrial areas.

Requirements of Glass-Sands

Up to the present time most manufacturers and writers have been inclined to emphasize the importance of chemical analysis, and to demand a very high standard of purity in the sand. Experimental work carried out since the opening of the war has tended to indicate that fairly pure British sands can be used with success for much good flint-glass work, thus tending to destroy the fetish of "nothing but Fontainebleau." Indeed, a few of the managers who have studied the technique of their work place the question of the evenness of grain of their sands on an equality with, if not above, that of very high silica and very low iron-content. In the manufacture of glass other than that for optical purposes (where exceedingly pure sands are sometimes required) the mechanical analysis is of great importance.

1. *Chemical Composition.*—From the chemical point of view, sands for glass-making should have a very high silica-content, preferably over 98 per cent., and for the best work over 99·5 per cent.*; they should have a low iron-content, for the best glass-work below 0·05 per cent. Iron is always present in the heavy detrital minerals, as magnetite, limonite, or ilmenite, or in the form of silicates, etc., but since the heavy crop in a suitable glass-sand is always less than 1 per cent., it is not the iron so present which determines the suitability or otherwise of the sand. Even such a very pure sand as that from Fontainebleau contains a proportion of dense minerals, but its low iron-percentage is due to the absence of any coating of limonite (hydrated iron oxide) or hematite (Fe_2O_3) upon the quartz-grains. This iron-staining in sands, which is the cause

* See chemical analyses in Tables. In addition to these, Hohenbocka sand is said to contain 99·71 per cent., and sand from Nievelstein, in the Rhine Province, 99·97 per cent. of silica.

of the rejection of a large number of English samples, usually exists on the outside of the quartz and felspar grains, but is sometimes seen inside, due to subsequent growth of quartz after deposition of the pellicle of iron oxide. Inclusions of ferruginous material also occur in quartz and felspar, having been caught up and enclosed at the time of their crystallization.

The iron-percentage should therefore always be low, but a small amount present in the sand need not render it unsuitable, provided the mechanical analysis is satisfactory, for much good glass-work, such as lamp chimneys, globes, laboratory-ware, etc. The green or yellow colour due to iron may be corrected by the addition of decolorizers (including oxidizing agents or oxygen carriers) such as manganese dioxide, white arsenic (As_2O_3), nickel oxide, selenium, etc.

Glassy rocks, such as obsidian, tachylyte, etc., which are produced by the rapid cooling of igneous magmas, similarly owe their dark green, black, or brown colour to the presence of compounds of iron, alumina, lime, etc. Similar "black" or dark green bottle-glass may obviously be made from impure sands.

In consequence of the demand for a high silica-percentage, the sands used are almost entirely composed of quartz-grains. The presence of felspar-grains in a glass-sand is desirable for many purposes, but, unfortunately, it generally means an increase in iron and other constituents. The usual method, therefore, of obtaining the required amount of alumina and alkalies is to add pure felspar, alumina, and salts of potassium and sodium to the batch. Sands low in iron are for the greater part very free from other constituents also, rarely containing, except as traces, substances other than alumina. To yield the proportion of alumina required for certain glasses, a sand consisting of 40 per cent. to 60 per cent. of felspar would be required. Such sands, if they are to be free from iron oxide and certain other substances, are very rare, and indeed could only result from the denudation of such a rock as a very pure quartz-porphyry or a pegmatite, with no admixture from any other source. In Chapter IV. (page 36) the Thuringian Forest sand, bearing 3·66 per cent. of alumina, was mentioned as being especially suitable for the making of thermometer-glass.

Calcareous sands are of frequent occurrence, but are to be avoided. The calcareous material is often sporadic in its distribution. The Fontainebleau deposit is well known to geologists for the beautiful steep rhombohedral crystals made up completely of sand-grains, just cemented by calcite into the crystal shape. The sand used for glass-work is selected free from this calcareous material, but occasionally the supplies received in Britain contain a few chalk-cemented balls. These are objected to when found, but usually all the consignments are similar in their purity and remarkably true to sample. Other impurities also tend to occur in calcareous sands; and lime itself is an undesirable constituent in sands used in the manufacture of certain kinds of glass.

2. *Mineral Composition.*—The mineral composition is useful as giving an indication of the relative amount of heavy detrital minerals present in the sand, and the quantity of quartz and felspar in the lighter crops. Sands with large crops of heavy minerals can only be used for rough bottle-glass. Indications of the presence in quantity of minerals other than quartz are, of course, yielded by the chemical analysis. Mineral analysis is, however, a shorter and less tedious process, and like the spectroscopic examination of sands, reveals the presence of small quantities of the less common elements. Naturally-panned sands—namely, those in which the heavier minerals have been concentrated as a result of oscillation produced by currents of wind or water—must be avoided, even if, as in some cases, they are white and clean-looking. Iron minerals frequently make up a considerable bulk of a heavy residue. Sometimes, by the combined effects of wind-action and screening by vegetation (as in some of the Irish dune- and beach-sands), a kind of winnowing action takes place by which they may be purified locally from heavy minerals. Most of the British sands of this character are made up of mineral material derived from many sources, and while yielding interesting mineral assemblages (including micas in English, Scotch, and Irish samples, although Retgers states that these minerals do not occur in Dutch dune-sands) are, in spite of being washed free from some adherent limonite and clay, of little use except for green bottle-glass work.

The presence or absence of certain minerals highly objectionable in glass-making may quickly be noted by mineral analysis. Zircon crystals ($ZrSiO_4$), if present in quantity, are very undesirable on account of their highly refractory character. They remain undigested in the "metal." Titanium minerals such as ilmenite ($FeTiO_3$), rutile (TiO_2) and its isomers, anatase and brookite (which are rarely abundant) are also detrimental to the making of good glass. Titanium is always an objectionable constituent of the "metal," and it so happens that ilmenite and rutile, like zircon, are among the most commonly occurring detrital minerals.

3. *Mechanical Composition* (see page 21 for description of apparatus, etc.).—Elutriation is carried out on the assumption that the sediment is composed entirely of quartz, or of minerals of the same density. Most sediments contain so small a percentage of heavier or lighter minerals, that the error introduced by them is less than that due to experimental causes.

Mechanical analyses of glass-sands, including many from abroad which are successfully used in the trade, indicate that the sand should have at least 70 per cent., and, if possible, more than 90 per cent., of one grade, and that this grade should be in most cases medium sand, *i. e.* with diameter between 0·25 and 0·5 mm. (0·01 to 0·02 inch). Although a "medium" sand in the geological sense, it is a fine looking material to the eye. If the true "fine sand" grade, 0·1 to 0·25 mm. diameter, forms the bulk of the deposit,

so much the better, but such sands are not abundant in the British Isles. A distribution of the bulk of the sand over these two grades is also not very objectionable, although glass-makers naturally prefer constancy of size. Grains over 1 mm. diameter in a sand reduce its value considerably, and it is best that none should have a diameter greater than 0·5 mm. diameter. If the extra expense is not prohibitive, a pure and fairly well-graded sand may be sifted by screens to rid it of grains over 0·5 mm. diameter. Of the few sands used in glass-making, containing the coarse grade, we may mention that from Leighton Buzzard in Bedfordshire (Lower Greensand). The sand as supplied has been washed, and contains 24·6 per cent. by weight of diameter between 0·5 and 1 mm., and 74·3 per cent. of diameter 0·25 to 0·5 mm. The latter grade is suitable and its percentage is fairly high, but it would be desirable if the other 25 per cent. were of the next smaller, and not the next larger, grade, as in the case of Fontainebleau sand, where the portion $>0·5$ mm. diameter $= 0·1$ per cent. or less, $>0·25$ and $<0·5$ mm. $= 70·6$ per cent., and $>0·1$ and $<0·25$ mm. $= 26·6$ per cent.

If the "batch" is ground fine before being melted the question of grade-size in the sand is obviously not of such moment, and high percentage of silica and low percentage of iron are the desiderata. Leighton sand was used in this way by one firm making chemical glass-ware, but it is doubtful whether much advantage accrues from the grinding except in the case of the best glass-ware. The extra expense is considerable.

As the Tables indicate, there are many British sands of which the mechanical analyses are similar to that of Fontainebleau sand. The regularity of grade of blown-sands in various other parts of the world has previously been commented upon, and the same holds true for British dune- and shore-sands. Although the evenness of these sands, due to selective transportation and deposition of material, renders them very suitable for glass-making, the colour, as previously remarked, shows the presence of too much iron and heavy mineral residues for the sands to be used for other than common bottle-glass. Dutch and Belgian sands imported into this country vary considerably in character. They are uniformly high in silica (some varieties containing pink quartz) and are used for other purposes, as well as glass-making, on account of their refractory properties. The colour and iron-content vary somewhat, but the grade-analysis, although variable, usually shows a high percentage (over 90) of the medium-sand grade. These are good all-round sands, and the nearest English equivalent in mechanical composition is the Lower Greensand obtained from near King's Lynn, in West Norfolk (Sandringham Sands). Many qualities of this sand are supplied, and the best has a colour and low iron-content equal to those of the best Belgian sand, as well as a high percentage (95 per cent.) of the desirable grade. Further notes upon the various qualities will be found under the remarks upon this source of supply.

British sands with a high percentage of the grade of "fine sand"

include those of the uppermost Thanet Beds from the well-known Charlton pit in Kent, and the Kelloway Beds of Burythorpe, near Malton, Yorkshire. The fineness of their dominant grade and its high percentage (nearly 70 per cent. diam. > 0·1 and < 0·25 mm.) are advantageous.

In the Tables the cumulative percentage of all the sand-grades (> 0·1 and < 1 mm. diameter) is given in a separate column (S). This should approximate to 100 per cent. for glass-sands, and rarely be less than 95 per cent. The grade of diameter > 0·01 mm. and < 0·1 is best termed the silt-grade, but actually the coarser material of this grade is a superfine sand. It is therefore sometimes desirable to estimate it in two portions: (*a*) superfine sand of diameter > 0·05 mm., (*b*) silt of diameter < 0·05 mm. Certain deposits, for example, are certainly sands, but contain a high percentage of the grade > 0·01 and < 0·1 mm., the grains composing which are mostly above 0·05 mm. diameter. Such are the sands of the Inferior Oolite from Bridport, Midford, Yeovil, the Cotteswolds, etc., which show a remarkable uniformity of grade over a large area.

These Inferior Oolite Sands are unfortunately yellow in colour, contain much iron oxide, and heavy crops of dense minerals. They are occasionally calcareous, but clear rapidly to fine white micaceous sands on warming with dilute acid. Their use for glass purposes is therefore at present ruled out. Sands of this extremely fine grade are rare in the British Isles.

Sands to be used for glass-making should not contain much of the silt-grade. The clay-grade, of diameter < 0·01 mm., certainly should be absent. The percentages shown in the tables were estimated by difference (see page 23). The figures in this column, therefore, include hygroscopic water (some of the samples were air-dried at first, and all the grades were dried at 100° C. before weighing), dust accumulated by exposure and during transit of the sand, the limonitic coating on grains in some cases, and films of soluble or other salts (*e. g.* sea-salts in the dune- and shore-sands). Probably this grade is practically absent in most cases where it is recorded as less than 0·5 per cent.

Such sands as those of Triassic age from Worksop in Nottinghamshire, and Spital in Cheshire, actually contain clayey and silty material (including kaolin). Some of the clayey and dusty matter coats the grains of quartz and felspar. The Tables indicate that, although they are fairly clean sands, they are not sufficiently well-graded to be suitable for the making of other than common glass.

Mechanical analyses of American and Danish glass-sands are appended for comparison (see pages 168, 169, 170).

The use of pot- or tank-furnaces has an important bearing on the grade of the sand used for the batch. When a poorly-graded sand, containing much fine powdery silica, is used in the batch for a tank-furnace, considerable loss due to "blowing-out" results. The other constituents such as compounds of the alkalies, which may

be in the form of fine powder, melt more rapidly, and so are not lost*. A considerably higher temperature must be attained before silica fuses; fine material is therefore carried away by the blast of gas and air before it melts. Not only does a real loss in bulk thus occur, but the resulting composition of the batch is changed. When melting takes place in pots, this loss by blowing-out is obviated. Silica in a fine state of division in a sand is also open to objection on other grounds. Air-bubbles entangled in the fine material are introduced into the "metal" from which they are removed only with great difficulty. The fine particles melt before the coarser ones, and the resulting metal sinks to the bottom. The density of the molten material thus formed is not constant, and varies as the pot is depleted of its contents. If coarse grains are present, the batch takes longer to melt, or these remain as undigested or partly digested lumps in the glass ("seeds" or "stones"). The results, therefore, of using non-graded sands are unsatisfactory. The value of such a sand as that of Fontainebleau lies in the way in which the whole of the batch containing it passes smoothly into the molten condition at almost the same moment. Angularity or subangularity of the grains may contribute to rapid melting.

No arrangements for stirring the metal exist in most furnaces. The result of using imperfectly-graded sands is therefore the production of "metal" of unequal composition, texture, and density, with consequent trouble in working. Clayey materials also tend to cloud the glass, and kaolin itself is highly refractory and formerly rendered unsuitable a sand containing it.

The statement in an American publication (U. S. G. S. Bull. 285, p. 454) that sand of diameter less than $\frac{1}{60}$ inch burns out in the batch, giving less glass, is not borne out by British and Continental practice, where so much of the sand used is of diameter less than $\frac{1}{60}$ inch. Sand of 20 to 50-mesh, advocated by American writers, appears to be coarser than British glass-manufacturers prefer to use.

4. *Angularity of Glass-Sands.*—The grains composing the sands in general use for glass-making in Britain are either angular or subangular in character. Sands containing rounded grains are not popular with some glass-manufacturers—indeed, angularity is preferred in England. The most obvious explanation of the preference for angularity seems to be that the grains fuse more rapidly, the process beginning at the corners and edges, the surface-area being greater, volume for volume, than that of rounded grains. Some of the Belgian sands are highly angular, having a sharp feel. Rapid melting is desirable and saves much time and trouble; thus both furnaces and sands are called upon to contribute towards this end.

* In many works it is found that alkali dust and not silica is carried over into the flues and chokes them. Careful filling of the batch does much to prevent the loss of fine material, but rapidity of filling is essential. Damping the batch has also been recommended.

Sands composed of rounded grains appear to be successfully used for glass-making in America (see Plate V, fig. 2)*.

In certain works where table-ware and bottles made of flint-glass have names and marks etched upon them by sand-blast action the sand used in the blast as the abrasive is the same Fontainebleau, Belgian, Aylesbury, or Lynn sand as that utilized in making the glass. Besides its marked angularity (so that its cutting power may be as great as possible), a sand for etching should be hard and tough. For common purposes a highly siliceous, *i. e.* quartzose sand is suitable. It must be perfectly dry and of even grade (not too coarse), in order that it may pass freely through the funnels, etc. and not clog the jets and stencil upon the sudden release of pressure. If water-vapour is present the adiabatic expansion and fall of temperature results in its condensation, and clogging takes place. Some sands used for grinding plate-glass are worked at Leighton Buzzard; others have been dredged from the bed of the River Mersey.

Variation according to the kinds of Glass produced.

For the commonest glass (bottle-ware, etc.) the mechanical analysis is of prime importance. The sand must be well-graded and composed of suitably-sized grains. Greater latitude in chemical composition is permissible than with better-class glasses. The silica-percentage should still be fairly high, but low iron-content is not so essential: it may vary up to 1 per cent. (as Fe_2O_3). The presence of small quantities of titanium, aluminium, calcium, and alkalies is but slightly harmful.

For all medium-class glass-ware, including the best bottles, chemical ware, globes, chimneys, pressed-ware, etc., both chemical and mechanical analyses are of great importance. High silica-content (and for much laboratory-ware, etc., high alumina) and low iron-content are demanded. Other constituents, if present at all, should be in minimum quantity. Good grading is extremely desirable, and the size of grain should not fall outside the limits of 0·5 and 0·1 mm. diameter.

For high-class glass-ware such as optical glass, table-glass (which is afterwards "cut"), and other special glasses, the chemical composition is of prime importance, and the mechanical analysis often, but not always, takes a secondary rank. In the famous cut-glass table-ware industry of the Stourbridge district, the batch is not at the present time ground fine, neither do arrangements exist for stirring the metal; in consequence the grade, as well as the chemical composition, must be of a high standard. For the other ware mentioned, a high percentage of silica (and at times alumina) is demanded, and little or no iron should be present. As the batch is sometimes pulverized and as stirring is occasionally adopted, the "metal" being allowed to remain molten for a long

* United States Geological Survey, Bull. 285, 1906, page 454. See also Mineral Resources, 'Sand and Gravel' for 1915 and earlier years.

period, crushed rocks and quartz, as well as poorly-graded sands, might be utilized.

Summary: The Ideal Glass-Sand.

A perfect "sand" in the geological sense, that is one composed entirely of grains belonging to one grade, which should not be a coarse one, yields the best material for glass-making, provided that the chemical composition is suitable. As a general rule, for all kinds of glass-work the iron oxide (Fe_2O_3) percentage should be low, always under 1 per cent., the higher limit being permissible only for glass for the cheapest class of bottles. As already stated, the sand used for the best varieties of glass, such as optical glass, best flint- and sheet-glass, best Bohemian glass, "crystal" table-ware, etc., should contain at the most only a few hundredths (·02 to ·08) per cent. of iron oxide. Alumina, magnesia, and lime may be present in sands in the form of felspars, ferromagnesian and lime-bearing minerals, and calcareous cement, but are required only for certain glasses. These bases are very refractory and lengthen the time taken for melting. Sands free from them are preferable, both because the bases are required only for refractory glasses, and then must be added in larger quantities, and because the presence of minerals containing them in sand usually means also the presence of a prohibitive quantity of iron. The specific properties of optical glass are altered by the presence of such impurities in the sand.

It is found desirable, therefore, to rely upon the sand only as a source of pure silica, and to add other bases for the purpose of making the various kinds of glass desired.

The ideal sand for the best glass-making is one with 100 per cent. silica and composed of angular grains all of the same size, and of the grade known as medium or fine sand. Such a perfect sand has not at present been discovered, but the ideal is approached by a few sands, including those of Fontainebleau in France (99·7 per cent. silica), Lippe in Germany (99·8 per cent. silica), and Berkeley Springs in the U.S.A. (99·65 per cent. silica). Sands from Lippe and Berkeley Springs are described in Chapter XI.

CHAPTER VI.

BRITISH SANDS SUITABLE FOR GLASS-MAKING.

The Tables of chemical and mechanical analyses on pages 154 to 170 give an indication, in the light of what has been said before, as to how far British sands may be used to replace those imported from abroad. In the first place, there does not appear to exist, anywhere in the British Isles, a sand so suitable, from all points of view, for the making of the best kinds of glass, as those from Lippe and Fontainebleau. The best sands from Aylesbury in Buckinghamshire and from Fairlight in Sussex are equal to Fontainebleau sand, and the sands from Huttons Ambo and Burythorpe in Yorkshire, and other places, are certainly as good as much of the Belgian sand imported. Lynn sand, at its best, is also equal to much of the Belgian material, and is superior to some of the Dutch sand. The same remarks apply to Godstone and Reigate sands (Lower Greensand, Surrey), but the deposits are irregular. A large number of British sands, especially dune- and shore-sands, are less pure, but are well suited to the making of common bottle-glass. Mechanical analyses of some representative examples of these are given in the Tables on page 165.

The writer is unable to agree with Dr. W. Rosenhain, who, in the Cantor Lectures before the Royal Society of Arts in 1915, said: "In this respect [*i. e.*, suitability of sands] glass-makers in England are unfavourably situated, since there are at present no very suitable sands available in this country. Whether exhaustive search might lead to the discovery of a suitable deposit is doubtful, because a large number of firms have already sought for good glass-making sands, and find it difficult to supply even the requirements for ordinary window (sheet) glass." Necessity, exploration, and experience under war-conditions has resulted in the use of large quantities of British sands for all kinds of glass of better quality than window-glass. The statement is also an exaggeration of the difficulties which existed before 1914.

Analyses and notes upon some important foreign glass-sands are given in Chapter XI. for purposes of comparison. A few mechanical analyses are graphically expressed in the curves of Figs. 10 and 11 (page 50).

No attempt has been made in the following pages to treat exhaustively British resources of common sands suitable for dark bottle-making. Such supplies are abundant and ubiquitous, and can be found at no great distance from the works.

The descriptions are given under the heads:—A. Purely siliceous

Fig. 10.—*Mechanical Analyses of Glass-Sands : Foreign.*

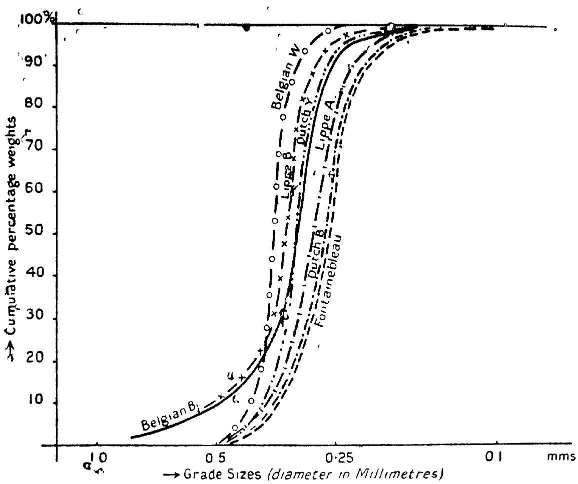
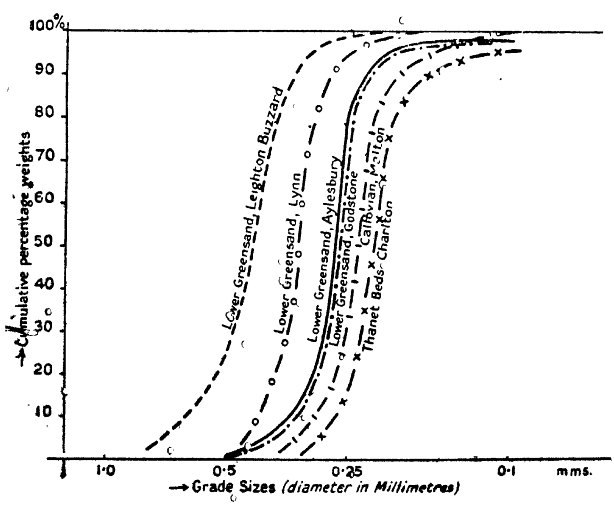


Fig. 11.—*Mechanical Analyses of Glass-Sands : British.*



materials, including (*a*) sands, (*b*) crushed rocks; B. Siliceous deposits carrying (*a*) alumina, and (*b*) alumina and potash

A. Purely Siliceous Deposits

(*a*) Sands.

§ "Aylesbury" Sand.

Worked by The Aylesbury Sand Company. Manager, Mr. J. Arnold (Offices, 32 St. Paul's Road, Camden Town, N.W. 1).

Maps.—Geological: Old Series 1-inch, Sheet 46 S.W.

" 6-inch Buckinghamshire, Sheet 32 N.W.

Situation.—*Lat.* 51° 48′ 22″, *Long.* 0° 52′ 5″ W.

The quarries occur at Stone, three miles west of Aylesbury. The sand is also exposed in the "Windmill" pit, but is not worked there to any extent.

Formation.—Lower Greensand.

Description.—White seams of pure sand, suitable for flint-glass work, extend to a depth of about eighteen feet. Working is then stopped by water. Peaty and ferruginous bands occur, and since the seams of white sand are not very thick (four to six feet) or persistent, working is rather difficult. It is not easy to ensure that successive consignments conform to the highest standard of purity met with, and variability is abhorred by glass-makers. The whiteness and purity may be connected with the peaty bands. The colour is good. the best Aylesbury sand being better than Belgian, and selected samples being equal to Fontainebleau sand. Washing does not improve the colour of the best sand to any extent, but a second-quality sand, washed free from limonitic and clayey pellets (in rotary washing-plant), is also supplied. The latter sand is pale grey, but reddens slightly on burning, whereas the former shows little or no change. The chemical composition is as follows:—

	Best sand.	Washed sand as delivered.	Bulk sample.
SiO_2	99·80	99·39	98·76 per cent.
Al_2O_3	0·32	0·48	0·37
Fe_2O_3	0·03	0·02	0·03
CaO	n. d.	n. d.	0·17
MgO	n. d.	n. d.	0·10
Na_2O	n. d.	n. d.	none
K_2O	n. d.	n. d.	0·04
Loss on ignition	0·22	0·13	0·33
Totals	100·37	100·02	99·80 per cent.

The evenness of grade is a marked feature, the sand in this respect very closely resembling Fontainebleau (see Plate III. figs. 1 & 3). The mechanical composition is as follows:—

§ Sections marked thus deal with sands and rocks which are also of use as refractory materials.

>0·5 mm., few grains only; >0·25 & <0·5, 78·3 %; >0·1 & <0·25, 15·0 %; >0·01 & <0·1, 5·8 %; <0·01, 0·9 %. Total sand-grade, >0·1 mm., 93·3 %.

$$\left[\frac{CS}{tr.}, \frac{MS}{78{\cdot}3}, \frac{FS}{15{\cdot}0}, \frac{s}{5{\cdot}8}, \frac{c}{0{\cdot}9}; \frac{S}{93{\cdot}3}\right]$$

The detrital mineral suite is very characteristic of the Lower Greensand throughout England. Heavy minerals are fairly abundant (0·2 to 0·3 mm. diameter), and the residue consists almost entirely of coarse, angular kyanite, staurolite, and brown and blue tourmaline, together with iron ores (magnetite, limonite, and altered ilmenite), zircon, rutile, etc.

The sands, after being carted to Hartwell Siding near Aylesbury Station (G. C. Railway), were put on trucks, before the war, at 7*s.* 6*d.* per ton. At the time of writing the price is 10*s.* This is rather high, and freight charges increase it to about 15*s.* or 17*s.* 6*d.* by the time it reaches a glass-making district as far distant as London or Yorkshire.

The estimated quantity available in the area is two million tons*.

§ Sands from Fairlight and Hastings.

(1) FAIRLIGHT.

Worked occasionally for sand, Milward Estate (Agent: Mr. G. E. Barr, 23 Havelock Rd., Hastings).

Maps.—Geological: Old Series, 1-inch, Sheet 5.
6-inch, Sussex, Sheet 58 S.E.

Situation.—*Lat.* 50° 52′ 30″, *Long.* 0 38′ 36″ E.

The pit is situated by the roadside, close to, and immediately to the south of, Fairlight Church, east of Hastings.

Formation.—Ashdown Sands (Wealden).

Description.—The bed of snow-white sand occurs at the base of the Ashdown Sands and immediately above the Fairlight Clays, of which a splendid succession is exposed in the cliffs below the Church. Glass-sands were recorded as having been worked at Hastings long ago †; they were doubtless sands like those exposed in this pit, and in that at Bulverhyth described below. The association of lignites with the Ashdown and Tunbridge Wells Sands has been recorded by Topley ‡ and others, and the reducing action of the vegetable matter probably accounts for the freedom from ferruginous compounds. Fairlight Church stands towards the eastern end of a strong sandstone ridge overlooking Hastings. For two or three miles this ridge has, as its backbone, the white Ashdown Sands which are mentioned above. In an old quarry

* In each case the estimate of the resources is by the writer, and is to be taken as well within the upper limit.

† Mineral Statistics: Memoir Geol. Survey, 1860, p. 375.

‡ W. Topley, "The Geology of the Weald," Mem. Geol. Survey, 1875, page 395; Ashdown Sands, pages 59, 80; Tunbridge Wells Sands, pages 78, 85, etc.

about a quarter of a mile west of the Church, a wall of about twelve feet of white sandstone, not bottomed, is shown over about a hundred yards of quarry face. Water stands in the quarry. The deposit is well jointed and bedded and easily workable. Only three to six feet of valueless overburden occur above the white sands in the Church pit. The beds yield a firm solid face, many of the joints being superficially dirt-stained. A sample, which is almost as pure in colour as Fontainebleau sand, burned up slightly pink. Its chemical composition is as follows:

SiO_2	99·47 per cent.
Al_2O_3	0·24
Fe_2O_3	0·002
CaO	0·29
MgO	trace
Loss on ignition	0·20
Total	100·202 per cent.

The high percentage of silica and low percentage of iron are noteworthy. This sample was not intentionally selected, but happened to be very low in iron. Another sample from the same bed contained 0 016 per cent. of iron oxide.

The mechanical analysis shows:—

$>$0·5 mm., none; $>$0·25 & $<$0·5, 83·7 %; $>$0·1 & $<$0·25, 16·1 %; $>$0 01 & $<$0·1, 0·1 %, $<$0·01, 0·1 %. Total sand-grade, $>$0·1 mm., 99·8 %.

$$\left[\frac{\text{MS}}{83{\cdot}7}, \frac{\text{FS}}{16{\cdot}1}, \frac{\text{s}}{0{\cdot}1}, \frac{\text{c}}{0{\cdot}1}, \frac{\text{S}}{99{\cdot}8}\right]$$

Washing would doubtless improve the deposit both chemically and mechanically.

The mineral composition indicates the presence of a few stable heavy detrital minerals in very small quantity, the proportion of density greater than 2·8 being only 0·01 per cent. The heavy residue is rather fine in grain, and the assemblage of minerals uninteresting. All the readily decomposable compounds have been eliminated before or since deposition. A little magnetite occurs, and limonite in small quantity is seen. Ilmenite is abundant (0·2 mm. diameter), but practically always altered to leucoxene. Brown tourmaline (0·15 mm.) is plentiful, and zircon (0·1 mm.), reddish rutile (0·1 mm.), and muscovite (flakes 0·2 mm. diameter) occur.

The most serious consideration is that of transport. A good road links the pit to Hastings, the Station (L. B. &. S. C. and S. E. & C. Railways) and quay being four miles distant. The road is, however, downhill all the way, and motor-traction should be economically possible. The sand might then be shipped at Hastings. An alternative suggestion is that of taking the sand eastwards down to Cliff-End, near Winchelsea, and shipping it from there. The nearest station to Fairlight is actually Ore (three miles), but it is badly situated in a hollow with a steep

gradient from the pit. The proximity of the London market and the possibility of water-transport to an even greater distance are noteworthy.

The available resources are over fifteen million tons.

(2) BULVERHYTH, WEST OF HASTINGS.

Worked occasionally for sand. Filsham Estate (Agent: Mr. T. W. Ellworthy, 81 London Rd., St. Leonards).

Maps.—Geological: Old Series, 1-inch, Sheet 5.
6-inch, Sussex, Sheet 71 N.W.

Situation.—*Lat.* 50° 51′ 0″, *Long.* 0° 32′ 18″ E.

The pit lies by the side of and north of the main road from St. Leonards to Bexhill. It is situated half a mile west-south-west of St. Leonards (West Marina) Station (L. B. & S. C. Railway).

Formation.—Ashdown Sands (Wealden).

Description.—The great thickness of overburden (about 30 feet), consisting of brown sands, silts, and clays, renders doubtful the profitable working of the few feet of white sands at the base. The strata dip to the north into the rising ground, so that shallow excavations farther northward are unlikely to reach the bed. The ground falls towards the west, and, on the opposite side of the small lane which runs northward by the western end of the pit, the glass-sands crop out at the surface. Although they do not appear to be so pure here, improvement might be seen as they are worked inwards. The white sand is similar in chemical and mechanical composition to that at Fairlight described above. The iron-content is 0·04 per cent., and the grade-analysis is as follows:—

>0·5 & <1 mm., 0·8 %; >0·25 & <0·5, 77·9 %; >0·1 & <0·25, 20·3 %; >0·01 & <0·1, 0·5 %; <0·01, 0·5 %. Total sand-grade, >0·1 mm., 99·0 %.

$$\left[\frac{\mathrm{CS}}{0{\cdot}8},\ \frac{\mathrm{MS}}{77{\cdot}9},\ \frac{\mathrm{FS}}{20{\cdot}3},\ \frac{\mathrm{s}}{0{\cdot}5},\ \frac{\mathrm{c}}{0{\cdot}5};\ \frac{\mathrm{S}}{99{\cdot}0}.\right]$$

The mineral composition is also similar to that of the sand from Fairlight, but the heavy crop is distinctly coarser in grain. The most common minerals, in order of abundance, are ilmenite, altering to leucoxene, grey-brown tourmaline (0·1 mm. diameter), foxy-red and, less commonly, yellow rutile (0·1 to 0·25 mm.), zircon in pinkish, purple, brown, and zoned crystals (0·1 to 0·25 mm.), and muscovite flakes, the average diameter of which is about twice that of the other grains.

The pit is favourably situated for transport, being at the side of a main road, and only a quarter of a mile from West St. Leonards Station (S. E. & C. Railway). Small quantities of the white sand have been carted to the station for despatch.

The available resources are under a million tons.

§ Sand from Ashurstwood, near East Grinstead.

Not at present being worked.

Owner.—Mr. A. H. Hastie, 65 Lincoln's Inn Fields, W.C. 2.

Maps.—Geological: Old Series, 1-inch, Sheet 6.

6-inch, Sussex, Sheet 5 S.W.

Situation.—*Lat.* 51° 6′ 50″, *Long.* 0° 1′ 15″ W.

Large excavations at Ashurstwood, particularly in Cherry Garden, north and north-west of the Church, south-east of East Grinstead, yield evidence of extensive early working.

Formation.—Tunbridge Wells Sands (Wealden).

Description.—The sand stands up in firm faces and blocks, sufficiently so to be described as a soft sandstone. The combined effect of weathering and excavation is to yield picturesque "rocks," the creamy-colour of the sand being subdued upon the weathered surfaces. A considerable thickness is indicated. Some of the seams are ferruginous, and washing would doubtless improve the whole deposit.

Samples of the sand, creamy-white in colour, turn browner on burning. The chemical composition is as follows:—

SiO_2	98·77 per cent.
Al_2O_3	0·73
Fe_2O_3	0·01
CaO	0·14
MgO	trace
Loss on ignition	0·43
Total	100·08 per cent.

The sand is small in grain, and the mechanical analysis indicates:—

>0·5 mm., a few grains only; >0·25 & <0·5, 9·8 %; >0·1 & <0·25, 85·5 %; >0·01 & <0·1, 2·0 %; <0·01, 2·7 %. Total sand-grade, >0·1 mm., 95·3 %.

$$\left[\frac{CS}{tr.}, \frac{MS}{9{\cdot}8}, \frac{FS}{85{\cdot}5}, \frac{s}{2{\cdot}0}, \frac{c}{2{\cdot}7}; \frac{S}{95{\cdot}3}\right]$$

The heavy residue is abundant and fine-grained, amounting to 0·24 per cent. It consists largely of zircon, yellow and foxy-red rutile, ilmenite, and tourmaline of about 0·05 mm. diameter. Although the crop is abundant, the mineral assemblage is not very interesting. Muscovite (flakes 0·5 to 0·6 mm. diam.), glauconite, and yellow anatase also occur.

The pits are situated about two miles from East Grinstead Station and a mile and a half from Forest Row (L. B. & S. C. Railway). There is a good road connecting them. Road-traction to London, about thirty miles distant, might also be possible.

The available resources are over fifteen million tons.

§ "Lynn" Sand.

(1) *Worked* by Messrs. Joseph Boam, Ltd. (Offices, Silver Street, Leicester). (See Plate VI., and also Plate IV. fig. 6.)

Maps.—Geological: Old Series, 1-inch, Sheet 65.
6-inch, Norfolk, Sheet 33 S.E.

Situation.—*Lat.* 52° 44′ to 52° 45′, *Long.* 0° 28′ to 0° 29′ E.

The sand is worked over an extensive area at Middleton and Gayton, three miles east of King's Lynn, and numerous scattered quarries occur.

Formation.—Sandringham Sands (Lower Greensand).

Description.—The deposit is fairly persistent and thick, so that large supplies of sand running true to sample can be supplied. Little variation occurs in successive consignments. The sand is won for foundry-work, glass-making, building-purposes, etc. The red sands are used for the last-named purpose and also for the making of black-bottle glass. In considering the sands suitable for general glass-making, it is to be noted that the colour of the best Lynn sand is equal to that of the Belgian, but most of the sand is rather darker, three qualities, besides a washed and a double-washed sand being supplied. Rotary washing-plant is employed. The washed sand has a pale grey to brown colour. The iron-content is rather higher than that of Aylesbury sand, and on burning there is a marked change to redder or greyer tints. The chemical composition of the best sand is as follows:—

SiO_2	99·23 per cent.
Al_2O_3	·59
Fe_2O_3	·04
CaO	·11
MgO	·02
Loss on ignition	·25
Total	100·24 per cent.

Note.—A duplicate determination of the silica and also of the alumina carried out as a control gave the figures 99·20 % and 0·56 %, respectively.

In mechanical composition the sand is seen to be well-graded, but rather coarser than either Aylesbury or Fontainebleau sand. The curve representing its composition in Fig. 11, page 50, is therefore sympathetic with, but to the left of, those for Aylesbury, etc., sands. Typical analyses yield the following results:—

>0·5 & <1 mm., none; >0·25 & <0·5, 94·8 %; >0·1 & <0·25, 4·9 %; >0·01 & <0·1, 0·2 %; <0·01, 0·1 %. Total sand-grade, >0·1 & <1 mm., 99·7 %.

$$\left[\frac{\text{MS}}{94{\cdot}8}, \frac{\text{FS}}{4{\cdot}9}, \frac{\text{s}}{0{\cdot}2}, \frac{\text{c}}{0{\cdot}1}; \frac{\text{S}}{99{\cdot}7}\right]$$

From the point of view of glass-making, the remarkably good grading of the sand calls for special note. Although not so low in iron-content as some other British sands, it is certainly the

most even in grain, and for that reason has been preferred by certain glass-manufacturers on account of its rapid melting. These remarks apply particularly to the sand from the pits near Middleton Station (G. E. Railway). This sand is washed to remove clayey and ferruginous matter, and a new washing-apparatus (Rikof's pattern) has recently been installed (see page 122 and Plate VII.).

The sands become less pure and more felspathic in the area near Gayton Road Station (Midland & G. N. Joint Railway). They are worked to a large extent for pale bottle-making, and are also of considerable use for furnace-hearths. A chemical analysis of a sample of one of these sands is as follows:—

SiO_2	97·34 per cent.
Al_2O_3	1·34
TiO_2	trace
Fe_2O_3	0·19
CaO	0·09
MgO	trace
K_2O	0·37
Na_2O	trace
Loss on ignition	0·76
Total	100·09 per cent.

The mechanical analysis of the same sample indicates:—

$>0·5$ & <1 mm., 0·5 %; $>0·25$ & $<0·5$, 95·1 %; $>0·1$ & $<0·25$, 2·7 %; $>0·01$ & $<0·1$, 0·8 %; $<0·01$, 0·9 %. Total sand-grade, $>0·1$ mm., 98·3 %.

$$\left[\frac{CS}{0·5}, \frac{MS}{95·1}, \frac{FS}{2·7}, \frac{s}{0·8}, \frac{c}{0·9}; \frac{S}{98·3}\right]$$

Greenish seams of glauconitic material are not uncommon, but as the glauconite (silicate of iron, aluminium and potash) is usually present as a coating to the grains of quartz, washing improves the sand considerably.

The mineral composition indicates rather more felspar than in the other Greensand deposits discussed (note Al_2O_3 percentage in chemical analyses). The heavy detrital mineral assemblage is similar to that of the Lower Greensand generally, but, in addition, occasional garnets are found.

The residue is a coarse one, the grains averaging 0·2 mm. diameter. The sand is extensively used for general glass-work, including window- and plate-glass, laboratory-ware, incandescent-lamp globes, chimneys, white and coloured bottles, etc. It has the great advantage of being cheap.

The prices of the sands put upon the market are as follows:— Brown Sand 3*s*. 6*d*. per ton, Unwashed White Sand 3*s*. 9*d*. per ton, Washed Sand 5*s*. 6*d*. per ton, Double-washed Sand 6*s*. per ton, Specially Selected and Double-washed Sand 8*s*. per ton, F.O.R. at Middleton Station (G. E. Railway) or Gayton Road Station (Midland & G. N. Joint Railway).

The washed sand is from the Middleton area, and the unwashed from near Gayton Road Station, but further washing is being contemplated.

(2) *Worked* by Messrs. Gay & Wilson (Managing Partner, Mr. G. W. Smart).

Maps.—Geological: Old Series, 1-inch, Sheet 65.
6-inch Norfolk, Sheet 33 N.E.

Situation.—*Lat.* 52° 46′ 0″, *Long.* 0° 29′ 0″ E.

Formation.—Sandringham Sands (Lower Greensand).

Description.—The quarries occur immediately north-west of Bawsey Signal Box, about a mile north-east of Gayton Road Station (M. & G. N. Joint Railway). The description given above applies equally well to these deposits, except that the sand is on the whole rather finer in grain and contains more iron (0·16 per cent.). The results of mechanical analysis are given in the Tables on page 163. The pits reveal a thirty-foot wall of sand (at times approaching forty feet where excavations have been made in the floor of the pits), in places rather regular in quality, capped by Glacial Drift, which occasionally forms pockets.

The sand is used to a considerable extent in the Yorkshire district for bottle-making, and also in the manufacture of soap. It is put on truck at Bawsey siding, Gayton Road Station, at from 2*s.* 2*d.* to 3*s.* per ton, a better quality also being selected when desired and supplied at a correspondingly higher price.

The available resources in the Lynn area are at least three hundred million tons.

§ "Leighton Buzzard" Sand.

Worked by (1) Mr. Joseph Arnold, (2) Mr. George Garside, (3) Mr. Gregory Harris.

Maps.—Geological: Old Series, 1-inch, Sheet 46 N.W.
6-inch, Bedfordshire, Sheet 28 N.E.

Situation.—*Lat.* 51° 56′ 15″ to 51° 57′ 10″, *Long.* 0° 38′ 20″ to 0° 39′ 10″ W.

The sand is worked over a large area north and north-east of Leighton Buzzard. Numerous quarries and old workings occur (Mile Tree, Shenley Hill, Stone Lane, Chance's Quarry, etc.).

Formation.—Lower Greensand.

Description.—The deposits are worked for a variety of purposes, glass-making being subordinate.

Both chemical and mechanical compositions vary considerably. The coarse sands are supplied for water-filtration plant, concrete-making, grinding, etc. The highly ferruginous sand is used for building, and most of the pale-coloured medium-grained sands are worked and washed by a rotary method for foundry purposes, particularly in connexion with steel-casting. This is on account of the

high silica-percentage, there being very little felspar. For the greater part the sands are neither so pure and free from iron nor of so fine a grade as those of Aylesbury; they are therefore not so well suited for good glass. They are used for the making of pressed glass and laboratory-ware. The iron-staining is patchy in its occurrence, and the pale sands are thus impersistent. The whitish sands are again associated with peaty bands.

The chemical composition of some of the samples of glass-sands is as follows:—

	(1)	(2)	(3)	(4)
SiO_2	99·05	99·59	96·77	99·58 per cent.
Al_2O_3	0·23	0·25	1·77	0·27
Fe_2O_3	0·14	0·21	0·27	0·03
CaO	0·31	n. d.	0·15	0·22
MgO	0·08	n. d.	0·03	none
K_2O	none	none	0·60	none
Na_2O	none	none	0·02	none
Loss on ignition	0·31	0·27	0·63	0·13
Totals	100·12	100·32	100·24	100·23 per cent.

(1) Arnold's pits, washed.
(2) " " unwashed.
(3) " " a fine grade.
(4) Garside's pit.

For the most part, the sands are coarse, passing into fine quartzose and cherty gravels. The latter are screened and used for abrasive purposes, including the grinding of plate-glass. Seams of fine white and grey sand occur, but are not common.

The whitish and pale yellow sands supplied for glass-making are rather coarser than manufacturers like. A typical mechanical analysis is as follows:—

$>0·5$ & <1 mm., 24·6 %; $>0·25$ & $<0·5$, 74·3 %; $>0·1$ & $<0·25$, 1·0 %; $>0·01$ & $<0·1$, less than 0·1 %. Total sand-grade, $>0·1$ & <1 mm., 99·9 %.

$$\left[\frac{CS}{24·6}, \frac{MS}{74·3}, \frac{FS}{1·0}, \frac{s}{0·1}; \frac{S}{99·9}.\right]$$

The mineral composition is like that of Lower Greensand deposits generally. The description of the mineral assemblage of Aylesbury sand applies here.

The sand is put on boat upon the Grand Junction Canal, or on truck at Leighton Buzzard, at 6*s*. per ton (Arnold), and 6*s*. 6*d*. per ton (Garside).

The available resources are at least five hundred million tons.

The Lower Greensand of **Flitwick** (pit one-third mile north of the railway station, worked by Mr. Joseph Arnold) is similar, but less pure. Analyses of this sand are given in the Tables on pages 156 and 163.

§ **Sand from Godstone, Surrey.**

Worked by Messrs. Goodwyn & Sons, Granville Chambers, Portman Square, London, W. 1 (owner Sir W. R. Clayton, Bart.).

Maps.—Geological: Old Series, 1-inch, Sheet 6.
6-inch, Surrey, Sheet 27 S.E.

Situation.—*Lat.* 51° 15′ 0″, *Long.* 0° 4′ 0″ W.

The pit revealing the whitest sand occurs half a mile north-west of Godstone Church.

Formation.—Folkestone Beds (Lower Greensand).

Description.—The whitest and best glass-sands occur as irregular patches in beds more iron-stained. No great supply of standard material can therefore be guaranteed, an unfortunate fact in view of its proximity to London and the Thames area. The pit is also some distance from a railway station. Sand has been sold for glass-making, but never in quantities of more than 20 tons a week, an amount hopelessly too small. The bulk of the deposit, consisting mainly of the upper beds, is worked for building-purposes, and some probably reaches London and is sold as silver-sand for soil-dressing and scouring purposes. The lower beds were used for the manufacture of glass.

Of the sands suitable for glass-making the colour is white to faint yellow, at its best almost equal to that of Fontainebleau sand. It changes to faint pink on burning. Washing would probably improve slightly some of the second-best sand, which would then serve for white bottle-work. The chemical analysis yields:—

SiO_2 .	99·56 per cent.
Al_2O_3	0·26
Fe_2O_3	0·06
Loss on ignition .	0·24
Total .	100·12 per cent.

From the point of view of glass-making the grade-analysis is good (Plate III. fig. 4). It is as follows:—

$>0·5$ & <1 mm., 0·6 %; $>0·25$ & $<0·5$, 73·0 %; $>0·1$ & $<0·25$, 25·7 %; $>0·01$ & $<0·1$, 0·2 %; $<0·01$, 0·5 %. Total sand-grade, $>0·1$ & <1 mm., 99·3 %.

$$\left[\frac{CS}{0·6}, \frac{MS}{73·0}, \frac{FS}{25·7}, \frac{s}{0·2}, \frac{c}{0·5}; \frac{S}{99·3}\right]$$

In mineral composition the sand closely resembles other deposits of the same age, such as those from Aylesbury, Leighton Buzzard, Lynn, etc., described. The list of minerals and description there given hold good for the Godstone deposits.

The price is 6*s.* 6*d.* per ton on truck at Caterham Station (S. E. & C. Railway).

§ **At Oxted** and **Limpsfield** in Surrey, about two to three miles east of Godstone, and at other places along the outcrop, the same sands (Folkestone Beds, Lower Greensand) are rather coarser in

character, the mechanical composition (see Table V on page 163) resembling that of Leighton Buzzard sand. More iron is present, and the sands burn redder, but they would be suitable for bottle-glass work. The mineral composition is again typical of the Lower Greensand.

Sands of the same age (Lower Greensand), but rather less pure, occur at **Westerham** in Kent and at other localities near.

Similar sands occur in the Folkestone Beds (Lower Greensand), in Sussex, *e. g.* near the village of **Rogate**. The overburden is, however, great, and the sands frequently contain patches of calcareous material.

§ Sand from Reigate, Surrey.

Worked (1) Doods Road Pit: by Mr A. B. Apted, Doods Road, Reigate; (2) Park Lane Pit: Agent, Mr. H. Sims, Old Town Hall, Reigate.

Maps.—Geological: Old Series, 1 inch, Sheet 8.

6-inch, Surrey, Sheet 34 N.E

Situation.—Doods Road Pit. *Lat.* 51° 14′ 25″, *Long.* 0° 11′ 0″ W.; Park Lane Pit. *Lat.* 51° 14′ 5′, *Long.* 0° 12′ 45″ W.

The smaller pit, in Park Lane, is situated about one-third of a mile south-west of the Castle, and the larger, Doods Road Pit, occurs by the northern side of the railway half-way between Reigate and Redhill.

Formation.—Folkestone Beds (Lower Greensand).

Description.—The Reigate sand is similar in age and character to that at Godstone, but the purer parts are of greater extent. The iron-staining is distributed in patches, but is never so serious as to prevent the sand being worked for second-quality glass (sheet-glass, pressed ware, laboratory-ware, etc.). Topley, in the "Geology of the Weald," stated (page 141) that Reigate sand was used for glass-making. The best seams of sand are equal in colour to Fontainebleau sand. The presence of calcareous material in places will probably necessitate washing. The chemical analysis is as follows:—

SiO_2	98·93 per cent.
Al_2O_3	0·67
Fe_2O_3	0·02
CaO	trace
MgO	none
K_2O	n. d.
Na_2O	n. d.
Loss on ignition	0·28
Total	99·90 per cent.

The mechanical analysis indicates:—

>0·5 & <1 mm., 2·7 %; >0·25 & <0·5, 79 %; >0·1 & <0·25, 14·5 %; >0·01 & <0·1, 1·8 %; <0·01, 2·0 %. Total sand-grade, >0·1 mm., 96·2 %.

$$\left[\frac{CS}{2{\cdot}7}, \frac{MS}{79{\cdot}0}, \frac{FS}{14{\cdot}5}, \frac{s}{1{\cdot}8}, \frac{c}{2{\cdot}0}; \frac{S}{96{\cdot}2}.\right]$$

The grading is rather variable, a gradual passage from coarse to fine sands being frequently observed. The mineral composition is typical of the Lower Greensand. The sands should be worked with care, both from the point of view of grade and of iron-content. That the available resources here are very great is indicated by the abundance of caves throughout the Reigate area. Large quantities of cream-coloured sand have been removed from these excavations. Doods Road Pit shows a 40-foot face of sand.

From the Doods Road Pit, selected fine silver sand is put on truck at Redhill Station at 6s. per ton (unwashed).

The available resources in the area are over one hundred million tons.

§ Sand from Aylesford, Kent.

Worked by Mr. Silas Wagon, Aylesford.

Maps.—Geological: Old Series, 1-inch, Sheet 6.
6-inch, Kent, Sheet 31 S.W.

Situation.—*Lat.* 51° 18′ 25″, *Long.* 0° 29′ 0″ E.

The pit exhibiting the whitest sand lies immediately north-east of Aylesford Church. The Nickle pit, a quarter of a mile west of the church, contains rather yellower sand (worked by the Nicopits Sand Company, Ltd.).

Formation.—Folkestone Beds (Lower Greensand).

Description.—Whitish sands with a northerly dip are covered in one part of the pit by the red ferruginous sandstone known as carstone. About twelve feet of the sand are worked, but the floor of the pit was covered with water at the time of writing. White chalky matter is often present. The general characters are similar to those of the other Greensand deposits described.

The colour is pale grey to cream, but the sand burns up pink.

The chemical analysis of the best sand is as follows:—

SiO_2	99·06 per cent.
Al_2O_3	0·56
Fe_2O_3	0·04
CaO	0·17
MgO	trace
K_2O	0·26
Na_2O	0·11
Loss on ignition ..	0·22
Total	100·42 per cent.

The grading is good, a mechanical analysis being as follows:—

$>$0·5 & $<$1 mm., few grains only; $>$0·25 & $<$0·5, 83·7 %; $>$0·1 & $<$0·25, 16·0 %; $>$0·01 & $<$0·1, 0·3 %; $<$0·01, none. Total sand-grade, $>$0·1 & $<$1 mm., 99·7 %.

$$\left[\frac{CS}{tr.}, \frac{MS}{83·7}, \frac{FS}{16·0}, \frac{s}{0·3}; \frac{S}{99·7}\right]$$

The mineral composition is that of the Lower Greensand generally, tourmaline, staurolite, and kyanite being large and conspicuous in the heavy mineral crop.

The sand is supplied on ship upon the Medway at Aylesford at 8*s.* per ton, and on truck at Aylesford Station (S. E. & C. Railway) at 9*s.* 6*d.* It is used for bottle-making at Queenborough, but would be of service for better glass.

The available resources are about five million tons.

Sand from Hollingbourne and Bearsted.

Not at present being worked.

Maps.—Geological: Old Series, 1-inch, Sheet 6.
6-inch, Kent, 43 N.W.

Situation.—Lat. 51° 16′ 0″, *Long.* 0° 35′ 30″ E.

The chief excavations, in the form of caves, lie nearly half a mile east-south-east of Bearsted Church, and one mile south-east of the railway station.

Formation.—Lower Greensand (Folkestone Beds).

Description.—Sands were stated to have been worked formerly at Bearsted, Hollingbourne, and Aylesford*, for making the commoner kinds of glass, "about 1000 tons being annually shipped." The caves at present existing at the first two localities testify to the extent of the former working. The sands are similar in character to those of the same age at Aylesford, Godstone, and Reigate, the caves being very similar to those of the last-named place. The sand is cream-coloured, turning after ignition to a browner tint. A chemical analysis yielded the following result:—

SiO_2	99·25 per cent.
Al_2O_3	0·31
Fe_2O_3	0·04
CaO	0·09
MgO	none
Loss on ignition	0·31
Total	100·00 per cent.

Alkalies absent.

A mechanical analysis yielded the following figures:—

>0·5 mm., none; >0·25 & <0·5, 94·6 %; >0·1 & <0·25, 4·2 %; >0·01 & <0·1, 0·8 %; <0·01, 0·4 %. Total sand-grade, >0·1 mm., 98·8 %.

$$\left[\frac{MS}{94{\cdot}6}, \frac{FS}{4{\cdot}2}, \frac{s}{0{\cdot}8}, \frac{c}{0{\cdot}4}; \frac{S}{98{\cdot}8}\right]$$

The mineral composition is similar to that of the Lower Greensand generally (see pages 50, 54–59), the percentage of heavy detrital

* Mineral Statistics: Mem. Geol. Surv. 1860, p. 374.

minerals of density greater than 2·8 being 0·026. Large kyanite (0·4 mm. diameter), staurolite, and tourmaline grains (0·2 mm.) are abundant; ilmenite, zircon, rutile, and limonite (0·1 mm.) are common, and flakes of muscovite mica (0·6 mm.) are also present.

The sand requires to be carted one mile by road to the nearest station, *Hollingbourne (S.E. & C. Railway); Bearstead Station is about two miles away by road.*

The available resources in this district are over twenty million tons.

Lancashire Sand.

Worked by a considerable number of glass-manufacturers and sand-merchants.

Maps.—Geological: Old Series, 1-inch, Sheet 89 S.W.
6-inch, Lancashire, Sheets 92 N.E., S.E.; 100 N.E., S.E.; 101 N.W., S.W.

Situation.—*Lat.* 53° 28′ to 53° 33′, *Long.* 2° 44′ to 2° 50′ W.

The pits and excavations are situated in the belt of country running south-east to north-west from St. Helens to Ormskirk.

Formation.—Glacial Sands.

Description.—The sands are worked extensively for the making of bottles and window-glass (at and near St. Helens), also in connexion with the soap-industry. The deposits occur at Crank, Rookery, Rainford, Kings Moss, Upholland, Skelmersdale, etc.*, north-west of St. Helens, and are used locally, so that no great amount of transport takes place. Skelmersdale, the farthest distant, is about nine miles from St. Helens. The sands are brown, frequently dark brown, in colour, and are very peaty. They occur in a series of hollows now drained by the small streams which flow south-eastwards to St. Helens and Warrington, and so into the Mersey. In late Glacial or post-Glacial times, these hollows were doubtless badly drained, and became filled with vegetation which has yielded the present peaty material. The abundance of place-names containing "Moss" is very significant. The decomposition of the vegetable matter has had a reducing effect on the ferric oxide in the sands, and in many cases, by the action of the acid peaty waters, has dissolved the iron out. The sands are worked to the drainage-level, usually a depth of about four feet only, and the turned-over land is again devoted to agriculture. The sands are washed at the various localities where they are won, and it is interesting to see in operation all styles of washing, from the most primitive to the latest and most effective. In the former case, the sands are washed by being run into shallow troughs and boxes let into the ground, where the material is kept in motion by shovelling. Paddle-methods of washing are also used, as well as modern rotary, dredging, and worm appliances. Vegetable matter is screened off,

* The Shirdley Hill sands of the Geological Survey Memoir, "The Superficial Geology of S.W. Lancs." 1877.

and the water after washing is coffee-coloured with peaty and dissolved ferruginous compounds.

Mechanical analyses of washed and unwashed samples from Rainford are as follows:—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed	3·3 %	83·0 %	11·7 %	0·9 %	1·1 %	98·0 %
Washed	1·3	84·5	13·1	0·2	0·9	98·9

The material is thus fairly well-graded and of suitable size in grain.

Although the sand is of a medium brown colour even after washing, the iron-content is low. The following are chemical analyses of Rainford Sands:—

Washed.		*Unwashed.*	
SiO_2	96·59	Fe_2O_3	0·05 per cent.
Al_2O_3	1·72		
Fe_2O_3	0·03		
CaO	0·19		
MgO	0·08		
K_2O	1·05		
Na_2O	0·05		
Loss on ignition	0·43		
Total	100·14 per cent.		

Duplicate determination, K_2O, 1·01 % ; Na_2O, 0·08 %.

The available resources are over a hundred million tons.

§ Sand from Huttons Ambo, near Malton, Yorks.

Worked by The High Silica Sands Company, Commercial Street, Norton, Malton.

Maps.—Geological: New Series, 1-inch, Sheet 63.
Old " " " 93 N.E.
6-inch, Yorkshire, Sheet 141 N.E.

Situation.—*Lat.* 54° 5′ 50″, *Long.* 0° 51′ 40″ W.

Greyish and pale yellow sands occur at Sleights and Hutton Bank, and the working is in process of development.

Formation.—Upper Estuarine Series (Lower Oolites).

Description.—The sections at present exposed show in the lower part ten to seventeen feet of cream-coloured sands with a small admixture of kaolin. Black specks of ilmenite are in places rather abundant. The sand is improved by washing, which removes calcareous and aluminous material also. The kaolin may be an advantage in the making of certain glasses, and for other purposes

it is easily removed if desired. Unwashed, this deposit serves excellently for bottle-glass making and for lining the hearth-bottoms of steel furnaces. (See Plate IV. figs. 1 & 2.) One seam of the sand is extremely pure, but most will have to be washed. The sand reddens slightly on burning.

A chemical analysis of a washed sample is as follows:—

SiO_2	99·04 per cent.
Al_2O_3	0·84
Fe_2O_3	0·03
CaO	0·10
MgO	0·18
Loss on ignition	0·19
Total . .	100·38 per cent.

Before being washed, the sand contains 0·13 per cent. of iron oxide.

The mechanical analysis indicates:—

>0·5 & <1 mm., 1·4 %; >0·25 & <0·5, 84·9 %; >0·1 & <0·25, 7·5 %; >0·01 & <0·1, 4·1 %; <0·01, 2·1 %. Total sand-grade, >0·1 & <1 mm., 93·8 %.

$$\left[\frac{\text{CS}}{1\cdot4},\ \frac{\text{MS}}{84\cdot9},\ \frac{\text{FS}}{7\cdot5},\ \frac{\text{s}}{4\cdot1},\ \frac{\text{c}}{2\cdot1};\ \frac{\text{S}}{93\cdot8}\right]$$

The upper part of the sections reveals beds, twelve feet in thickness, of yellow and brown clayey sands with greyish carbonaceous layers. Much more "bind" occurs in these beds, and the deposit is of great value for refractory purposes such as steel-casting.

The chemical analysis of the latter refractory sand is as follows:—

SiO_2	83·8 per cent.
Al_2O_3	9·2
Fe_2O_3	1·6
CaO	0·6
MgO	trace
Loss on ignition	4·7
Total	99·9 per cent.

Anal.: S. Hewitt.

The sand is quartzose, felspar being much less abundant than in the Kelloway Beds. In mineral composition the sand does not exhibit a rich variety of minerals, the heavy residue being coarse (averaging 0·2 mm. diameter). Very little magnetite is present, but ilmenite is abundant. Limonite and leucoxene occur. Large red garnets are common, and also tourmaline, staurolite, deep red rutile, and zircon. Grains of serpentine are occasionally seen.

The workings have now been considerably developed, a seventy-yard face having been opened up. A siding from the N. E. Railway, between Castle Howard and Huttons Ambo, has been built. It is hoped that the sand will be delivered at Knottingley and other places in the Yorkshire area at 7*s*. to 9*s*. per ton. It is put on truck at Huttons Ambo at 3*s*. 3*d*. per ton.

The estimated resources are one million tons.

Sand from Burythorpe, near Malton, Yorks.

Working given up some years ago.

Maps.—Geological: New Series, 1-inch, Sheet 63.
Old „ „ „ 93 N.E.
6-inch, Yorkshire, Sheet 42 N.W.

Situation.—*Lat.* 54° 4′ 40″, *Long.* 0° 48′ 40″ W.

Whitish sands are exposed in several pits, the chief of which lies near the Fox Cover, and three-quarters of a mile north-west of Burythorpe Church.

Formation.—Kelloway Beds of the Jurassic.

Description.—As in the case of the country around Leighton Buzzard, Middleton and Gayton, Godstone, etc., the sand supports only a poor heath flora, by means of which its fairly extensive outcrop is vaguely defined. Some years ago it was worked for glass-sand, but the working was given up; it may be re-exploited shortly.

The sand possesses a slight brown tint, due to iron-staining, but the best quality is nearly white (cream-coloured). The tint becomes slightly browner on burning, but the original colour, which lies between those of Fontainebleau and Belgian sands, is not improved to any extent by washing, although calcareous material is removed.

The chemical composition is as follows:—

	Fox Cover Pit.	Burythorpe Park.
SiO_2	96·79	96·70 per cent.
Al_2O_3	1·63	1·49
TiO_2	n. d.	0·35
Fe_2O_3	0·22	0·07
CaO	n. d.	0·12
MgO	n. d.	0·07
K_2O	n. d.	0·84
Na_2O	n. d.	0·08
Loss on ignition	0·60	0·56
Totals . . .	99·24	100·28 per cent.

The dominant grade of the sand is smaller than that of foreign and also other British glass-sands, but this is an advantage, for the deposit is well-graded (see Plate III. fig. 5).

In the mechanical composition the grade-percentages are:—

>0·5 & <1 mm., few grains only; >0·25 & <0·5, 39·2 %; >0·1 & <0·25, 59·0 %; >0·01 & <0·1, 1·0 %; <0·01, 0·8 %. Total sand-grade, >0·1 & <1 mm., 98·2 %.

$$\begin{bmatrix} CS & MS & FS & s & c & S \\ tr., & 39{\cdot}2, & 59{\cdot}0, & 1{\cdot}0, & 0{\cdot}8; & 98{\cdot}2. \end{bmatrix}$$

The grains mostly consist of subangular clean quartz, but grains of turbid felspar are not uncommon. The heavy residue is abundant and consists of much fine-grained dark material (average diameter

0·1 mm.). *In character it most resembles the mineral assemblage of the Inferior Oolite, which is remarkably similar all over its outcrop across England, from the Dorset coast to Yorkshire.* Abundant magnetite and ilmenite occur, and colourless to pale brown and pink angular garnet grains (0·12 mm. diameter) make up most of the residue. Rutile is extremely plentiful and zircon is common (both about 0·1 mm. or less diam.). Staurolite and grey-brown tourmaline grains occur. Muscovite is present, but the diameter of the flakes (0·12 mm. diameter) is not much larger than that of the average for the rest of the grains.

The question of transport to the nearest railway station, Malton (almost 5 miles), the high railway freights, and also the distance to the nearest port are serious considerations. The great glass-making area of Yorkshire is, however, near at hand.

Some trial-borings and a trial-hole have recently been put down a short distance away in Burythorpe Park by the owner, R. B. Colton Fox, Esq. The best of the sand brought to the surface looks very promising, and subject to an improvement in the economic conditions specified above, development of the area may be expected. (For analyses, see Tables, pages 156, 162.)

The available resources in the area amount to three million tons.

Less pure sands in the Kelloway Beds are worked at **South Cave**, near the station (by Messrs. T. H. Lyon and Partner, of Norton, Malton). They are of service for white bottle-glass and much other ware. Similar sands occur at **Newbald.** At **Sancton,** near by, white micaceous sands are found in the Estuarine Series.

Sand from Denford, Northamptonshire.

Worked by the Ebbw Vale Steel, Iron & Coal Company, Ltd., Irthlingborough.

Maps.—Geological: Old Series, 1-inch, Sheet 52 N.W.
6-inch, Northamptonshire, Sheet 33 N.W.

Situation.—Lat. 52° 22′ 20″, *Long.* 0° 33′ 45″ W.

The pits, which have really been opened for the purpose of exploiting the Northamptonshire Ironstone below the sand, occur nearly one mile west-south-west of Denford Church.

Formation.—Estuarine Series (Inferior Oolite).

Description.—Sands occur at the same geological horizon near by at Corby, Wansford, Apethorpe, Blatherwyke, etc., and were mentioned as having been worked for glass-making about 1860. Unfortunately, the variability and limitation in quantity which detracted from the value of these affect also the Denford deposits. It might be possible to get a good average quality by washing, but the sand is too fine in grain to be easily washed without considerable loss (see page 122).

The sand is cream-coloured and burns up pink. A chemical analysis of an average sample is as follows:—

SiO_2	98·19 per cent.
Al_2O_3	1·23
Fe_2O_3	0·06
CaO	0·15
MgO	none
Loss on ignition	0·46
Total	100·09 per cent.

The effect of washing would be to remove certain ferruginous pellets that occur, and to reduce appreciably the iron-percentage, which is already low.

The sand is very fine in grain and is well-graded, a mechanical analysis indicating:—

$>$0·5 mm., none, $>$0·25 & $<$0·5, 2·9 %, $>$0·1 & $<$0·25, 92·3 %; $>$0·01 & $<$0·1, 3·0 %, $>$0·01, 1·8 %. Total sand-grade, $>$0·1 mm., 95·2 %.

$$\left[\frac{MS}{2{\cdot}9}, \frac{FS}{92{\cdot}3}, \frac{s}{3{\cdot}0}, \frac{c}{1{\cdot}8}, \frac{S}{95{\cdot}2}\right]$$

The sand carried an abundant and dark residue of heavy detrital minerals, the portion of density greater than 2·8 being 0·38 per cent. The residue is dark as a result of the preponderance of ilmenite, and the mineral assemblage resembles that of the Inferior Oolite generally in its outcrop across England. The following is a list of the common mineral species in order of abundance:—Ilmenite and iron ores, garnets, zircon, red rutile, kyanite, tourmaline, glauconite, staurolite, muscovite, and yellow anatase.

The available resources, owing to the variability of the beds, are probably small.

Sands of similar age (Inferior Oolite), but less pure, occur at **Tadmarton**, about four miles west-south-west of Banbury. The pit is situated half a mile east of Tadmarton Church (*Lat.* 52° 2′ 12″, *Long.* 1° 25′ 5″ W.), and is worked by Mr. H. H. Salmon. About sixteen feet of rather variable sands containing peaty layers may be seen. Some of the bands are more iron-stained, rendering the profitable working of the pit for glass-sands, in view also of the location, improbable. The sand is coarser than that from Denford (see Table of Mechanical Analyses, page 162), but the mineral composition is similar, large pink and brown garnets, large staurolite, grey-brown tourmaline, abundant ilmenite and iron ores, zircon, and red rutile being characteristic.

Sand from Longdown, near Southampton.

Worked by Messrs. Sandell Bros., 79 High Street, Southampton.
Maps.—Geological: New Series, 1-inch, Sheet 315.
Old ,, ,, ,, 11.
6-inch, Hampshire, Sheet 72 N.E.
Situation.—*Lat.* 50° 52′ 30″, *Long.* 1° 29′ 10″ W.

The pits are worked a little to the south-east of the hamlet of Longdown in the New Forest, and are situated about four miles west-south-west of Southampton West Railway Station (L. & S. W. Railway).

Formation.—Barton Sand (Upper Bagshot Beds).

Description.—Sand from Longdown, situated upon land in the New Forest belonging to the Crown, was mentioned as having been worked for glass-making, and sent to the north of England, as early as 1858*. It is said to have been nearly as white as the Isle of Wight sand, and to have cost 6*d.* per cubic yard. Assuming a cubic yard to contain 30 cwts., we should now consider this price exceedingly low.

Two sets of pits are at present being worked. At the western end may be seen a fifteen-foot section of fine-grained, cream-coloured sand, containing yellowish patches and streaks which are more plentiful near the top. The overburden is very small. At the eastern end of the excavation red and yellow sands form a thicker topping, and the white sand is less constant. The latter is worked down to ground-water level.

If the sand were washed the iron-content and grading would doubtless be much improved, but the washing-plant at present on the market is not well suited to the rather fine grain of the sand. Inevitable loss of fine sand would result. Washing improves the colour slightly, and samples of the sand on ignition become a rather darker brown. The chemical composition indicates:—

SiO_2	95·41 per cent.
Al_2O_3	2·35
Fe_2O_3	0·09
CaO	0·26
MgO	0·18
K_2O	1·33
Na_2O	trace
Loss on ignition	0·50
Total	100·12 per cent.

After being washed the sand contains 0·06 per cent. of iron oxide (as Fe_2O_3).

The deposit is fine-grained, mechanical analyses being as follows:—

	MS. >0·25 & <0·5mm.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade: >0·1 mm.
Western end ..	8·9 %	84·6 %	3·8 %	2·7 %	93·5 %
Eastern end ..	5·9	91·2	1·5	1·4	97·1

* Mineral Statistics: Mem. Geol. Survey, 1860, p. 374.

The heavy minerals of density greater than 2·8 constitute 0·08 per cent. of the whole. Large flakes (0·4 mm. diameter) of a greenish muscovite are very abundant. Brown tourmaline (0·1 mm.), kyanite (0·2 mm.), iron ores, including ilmenite (altered to leucoxene), magnetite and limonite, are plentiful. Zircon and rutile in small grains about 0·05 mm. in diameter occur commonly, and the presence of epidote and green hornblende (0·1 mm.) was also noted.

The sand is carted by road about two miles to Lyndhurst Road Station (L. & S. W. Railway), where it is put F.O.R. at 9*s.* per ton. Two miles cartage eastwards will also bring the sand to a small quay on Southampton Water owned by Messrs. Sandell Bros., the water-freight to the London area being about 2*s.* 6*d.* and to Bristol 3*s.* per ton before the war. The sand is at present being supplied to the Bristol area (railway-freight about 10*s.* per ton) for bottle-making, but it is sufficiently good for better quality glass.

The sand occupies several square miles of wooded country, and the available resources are certainly not under four million tons.

Sand from near Fordingbridge, Hants.

Working being undertaken by Mr. A. J. Terrill, Rosebank, Fordingbridge; Lyburn Estate, owned by Cecil Lee, Esq.

Maps.—Geological, 1-inch. New Series, Sheet 315.

6-inch, Wiltshire, Sheet 77 S.E.

Situation.—*Lat.* 50° 57′ 30″, *Long.* 1° 39′ 30″ W.

The locality is actually across the county boundary in Wiltshire, but Fordingbridge is the nearest town.

The pits occur near "No Man's Land" about five miles east-north-east of Fordingbridge, and nine miles south-east of Salisbury.

Formation.—Bagshot Sand.

Description.—Wide stretches of sandy heath occur in this area. For the greater part the sands have been bleached white, or are coloured grey by an admixture of peaty material. So far as the small excavations enable the observer to judge, a bed of pale grey sand at least six or seven feet thick (the greatest depth yet proven), and probably much thicker, extends over a considerable area.

The sand is pale brown in colour and becomes grey on ignition.

The chemical analysis of a bulk sample as collected is as follows:—

SiO_2	99·28 per cent.
Al_2O_3 .	0·17
TiO_2	0·07
Fe_2O_3 .	0·02
CaO	0·11
MgO . .	none
K_2O . ..	none
Na_2O	none
Loss on ignition .	0·27
Total . .	99·92 per cent.

Other unwashed samples contained 0·03 and 0·02 per cent. of iron oxide.

The sand is well-graded, as the following mechanical analysis shows:—

> 0·5 mm., none; > 0·25 & < 0·5 (screened), 88·3 %; > 0·1 & < 0·25, 11·2 %; > 0·01 & < 0·1, 0·3 %; < 0·01, 0·2 %. Total sand-grade, > 0·1 mm., 99·5 %.

$$\left[\frac{MS}{88\cdot3}, \frac{FS}{11\cdot2}, \frac{s}{0\cdot3}, \frac{c}{0\cdot2}; \frac{S}{99\cdot5}.\right]$$

In mineral composition, the material is similar to the Bagshot Sands over the whole area of their southern outcrop. The heavy crop forms 0·08 per cent. of the whole, and consists chiefly of ilmenite changing to leucoxene, staurolite, kyanite (0·25 mm. diameter), blue and brown tourmaline, zircon, and red rutile (0·1 mm.).

It is proposed that the sand should be carted by road about two and a half miles to the railway near Downton Station (L. & S. W. Railway) or to the River Avon for water-transport.

A large factory (East Mills) and water-power are available at Fordingbridge.

The estimated resources are over three million tons.

"Isle of Wight" Sand.

This sand was formerly worked for glass-making and is mentioned in older British and foreign text-books. It has not been worked for some years.

Maps.—Geological: New Series, 1-inch, Special Sheet, Isle of Wight. (Sheets 330, 331, 344, 345.)
6-inch, Hampshire, Sheet 93 S.W.

Situation.—*Lat.* 50° 40′ 0″, *Long.* 1° 33′ 50″ W.

The sand is one of the famous Alum Bay Sands, cropping out on the shore about four miles south-west of Yarmouth.

Formation.—Headon Hill Sands. White sands also occur in the Lower Bagshot Beds.

Description.—The sand is associated with beds of lignite. In places it possesses a good colour, almost equal to that of French glass-sand, and darkens only very slightly on heating. Patches of more ferruginous material, however, occur frequently in it.

The chemical analysis of an average sample of Headon Hill Sand yielded:

SiO_2	96·96 per cent.
Al_2O_3	1·90
Fe_2O_3	0·11
CaO	0·34
MgO	trace
Loss on ignition	0·64
Total	99·95 per cent.

So far as its use for glass-making is concerned, the mechanical composition leaves something to be desired.

	CS. >0·5 & < 1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & < 0·25.	S. >0·01 & <0·1.	C. <0·01	S. Total sand-grade >0·1 mm.
Headon Hill	—	3·8 %	84·0 %	9·7 %	2·5 %	87·8 %
Nr. Bagshot ..	—	8·1	76·2	10·7	5·0	84·3

The mineral composition is similar to that of the Bagshot Beds generally, the abundance of rutile, blue and indigo-coloured tourmaline, and rolled grains of staurolite being noteworthy.

The practice of using this sand appears to have been dropped since the 'eighties, probably as a result of the difficulty, from its position, of working it in quantity, the imperfect grading, and the ferruginous patches occurring in it.

Similar whitish sands, but not so pure, are met with in Whitecliff Bay, at the opposite end of the Isle of Wight.

The Bagshot Beds of the London Basin have not all been explored; but some bands, such as the pale sands of **St. George's Hill, Weybridge**, might be used for common glass. Whitish sands of similar age in the Bagshot Beds are now worked near **Lymington** and **Brockenhurst** in Hampshire, and near **Creechbarrow** and **Wareham** in Dorset, but are not sufficiently pure for the purpose required (see Table on page 164). Their grading is open to objection.

§ Sand from Charlton, Kent.

Worked by Mr. E. Gilbert; pit owned by Sir Spencer Maryon Wilson, Bart.

Maps.—Geological: New Series, London, Sheet 4.
6-inch, Kent, Sheet 2 S.W.

Situation.—*Lat.* 51° 29′ 10″, *Long.* 0° 2′ 15″ E.

Numerous excavations occur in the district, but sand is actually worked for glass-making at the large pit about a quarter of a mile north of the church.

Formation.—Thanet Beds.

Description.—The uppermost few feet of the Thanet Beds at Charlton are worked for rough green bottle-glass manufacture in the London District. The lower portion of the Thanet Beds (which are here seen resting upon the Chalk) is more clayey and is worked for the famous "Blackfoot" moulding-sand ("Erith" sand), which is sent to all parts of Great Britain and exported abroad (to Stockholm, India, etc.). The sand is coloured pale brown or grey and is suitable only for common bottle-glass. It contains a fair quantity of iron, and reddens on heating.

The chemical analysis is as follows:—

SiO_2	95·21 per cent.
Al_2O_3	2·43 "
Fe_2O_3	0·42
CaO	0·19
MgO	none
K_2O	0·89
Na_2O	0·19
Loss on ignition	0·88
Total	100·21 per cent.

The mechanical analysis indicates that the grade of "fine sand" is dominant, as in the Burythorpe deposit.—

0·5 & <1 mm., none; >0·25 & <0·5, 16·2 %; >0·1 & <0·25, 79·6 %; >0·01 & <0·1, 3·1 %; <0·01, 1·1 %. Total sand-grade, >0·1 & <1 mm., 95·8 %.

$$\left[\frac{MS}{16\cdot2}, \frac{FS}{79\cdot6}, \frac{s}{3\cdot1}, \frac{c}{1\cdot1}; \frac{S}{95\cdot8}\right]$$

In mineral composition the sand resembles the Thanet Beds generally along the southern outcrop, the detrital minerals being fairly abundant, and occurring in angular grains. Ilmenite (altering to leucoxene) and limonite (0·2 mm. diam.), zircon (0·1 mm.) and rutile (0·2 mm.) abound, and tourmaline (0·2 mm.), staurolite, ? andalusite, and flakes of muscovite (0·2 mm. diam.) are also found.

Rail and river are near, and the sand is supplied at about 3*s.* 6*d.* to 5*s.* per ton at the pit (1*s.* 6*d.* and upwards per "foot").

The available resources of glass-sands are over two hundred thousand tons.

Thanet Sand near **Rochester** is similarly worked for the bottle industry at Queenborough, Higham, etc.

§ Sand from Worksop.

Worked by Messrs. Jas. Turner & Son, Ltd., Kiveton Park, near Sheffield, and at Worksop.

Maps.—Geological: Old Series, 1-inch, Sheet 82 N.E.
6-inch, Nottinghamshire, Sheet 8 S.W.

Situation.—*Lat.* 53° 18′ 48″, *Long.* 1° 7′ 54″ W.

The quarry, in which the sand suitable for glass-making is exposed, lies about one-third of a mile west of Worksop Station (G. C. Railway).

Formation.—Lower Bunter.

Description.—The excavations being made for Messrs. Turner's new glass-works, which are in course of erection, have revealed an excellent section of Permian marls. The marls are purple and green in bands, and the basal Bunter Sands rest upon their wavy upper surface. Fifteen feet of pale-coloured sands are seen, of

which the lowest seven or eight feet are worked for glass-making. In places these sands have a pale greenish appearance, and certainly appear to have a better colour where they occur below ground-water level. This may be due to solution of ferric compounds by algal or bacterial action. It is proposed to treat this bed by tank-washing, but at present the sand is being shipped to the Tyneside glass-works just as it is quarried. The uppermost few feet of the pale sands contain ferruginous streaks and patches. Red sand, strongly current-bedded and rather coarse in grain, forms the upper part of the section, fifteen to twenty feet high. It is worked as an "open" moulding-sand and for building-purposes.

The glass-sand is pale brown in colour and darkens on heating. A washed sample analysed by Mr. J. H. Davidson, M.Sc., of the Department of Glass Technology in the University of Sheffield, gave the following result:—

SiO_2	95·10 per cent.
Al_2O_3	2·32
TiO_2	trace
Fe_2O_3	0·51
CaO	0·22
MgO	0·24
Loss on ignition	0·54
Alkalies, by difference.	1·07
Total	100·00 per cent.

An average sample of unwashed sand (as sent to the North of England) collected by the writer contained only 0·10 per cent. of ferric oxide.

The mechanical analysis is as follows:—

>1 mm., 2·0 %; >0·5 & <1 mm., 6·6 %; >0·25 & <0·5, 58·65 %; >0·1 & <0·25, 26·15 %; >0·01 & <0·1, 4·5 %; <0·01, 2·1 %. Total sand-grade, >0·1 mm., 93·4 %.

$$\left[\frac{VCS}{2\cdot0}, \frac{CS}{6\cdot6}, \frac{MS}{58\cdot65}, \frac{FS}{26\cdot15}, \frac{s}{4\cdot5}, \frac{c}{2\cdot1}, \frac{S}{93\cdot4}.\right]$$

The percentage of alumina in the sand is an advantage for bottle-making, as it strengthens the glass. The alumina is present partly as felspar, and partly as its decomposition product kaolin. Much of the latter washes out of the sand, and its presence is indicated by the high clay-grade in the mechanical analysis.

In mineral composition the deposit resembles many other Bunter Sands. Ilmenite is abundant but very much altered to leucoxene. Yellow-brown and grey tourmaline in highly rounded grains are very abundant. Pink garnets (0·2 mm.), angular staurolite, and apatite also occur. Zircon and red rutile (0·1 × 0·03 mm.) are plentiful.

The quarry lies by the side of the G. C. Railway from Sheffield to Retford (*viâ* Worksop), and the Chesterfield Canal, which has, however, fallen into disrepair, especially in the adjacent Norton

Tunnel. The sand is supplied F.O.R. at Worksop (unwashed) at 3*s*. 6*d*. per ton. It could be put on boat on the canal for about 4*s*. 6*d*. per ton.

The available resources are over six million tons.

At **Alderley Edge**, Cheshire, occur large tips of sand which have accumulated from the copper and lead mines (6-inch Map, Cheshire, 28 S.W. *Lat.* 53° 17′ 40″, *Long.* 2° 13′ 15″). The Keuper Waterstones are impregnated at this locality with galena (lead sulphide) and malachite (copper carbonate). The sandstones were formerly mined, and after being crushed were treated with acid to dissolve the metalliferous ores. The resulting sand was washed to recover as much as possible of the metallic salts, and has thus accumulated as waste material.

The acid treatment has doubtless removed part of the iron oxide, but about 0·12 per cent. remained in a sample tested. The sand is pale brown and becomes greyer after ignition. It is markedly felspathic. The alumina present in the felspar would add to the value of the sand for bottle-making, when the iron-content would certainly not be too high for pale bottles.

In consequence of the washing, the grading is fairly good, as the following analysis indicates:—

$>0{\cdot}5$ & <1 mm., 2·4%; $>0{\cdot}25$ & $<0{\cdot}5$, 76·9%; $>0{\cdot}1$ & $<0{\cdot}25$, 17·2%; $>0{\cdot}01$ & $<0{\cdot}1$, 1·6%; $<0{\cdot}01$, 1·9%. Total sand-grade, $>0{\cdot}1$ mm., 96·5%.

$$\left[\frac{\text{CS}}{2{\cdot}4}, \frac{\text{MS}}{76{\cdot}9}, \frac{\text{FS}}{17{\cdot}2}, \frac{\text{s}}{1{\cdot}6}, \frac{\text{c}}{1{\cdot}9}, \frac{\text{S}}{96{\cdot}5}.\right]$$

Unfortunately the deposits are not situated upon a coalfield or a bottle-making area, and it is doubtful whether it would pay to move the sand as far as either the Manchester or Yorkshire districts. The mines are situated about one and a half miles south-east of Alderley Edge Station (L. & N. W. Railway), the road being a good one and downhill.

Dune-Sands and Shore-Sands.

Although some of these sands, the analyses of which are given in the Tables (pages 157, 165), have been used for bottle-glass, no blown-sand or shore-deposit from the British Isles pure enough (with the exception of that from the Isle of Jura) and in sufficient quantity for the making of flint or better-class glass has yet been seen by the writer. The constituents of these sands have usually a very mixed origin; but if local derivation from decomposing pure sandstones or quartzites can be ensured, suitable sands may be found. Usually, in dune- and shore-sands, current-action tends to defeat this object. Nevertheless, the dune- and shore-sands of the United Kingdom (especially those bordering the Archæan areas of Scotland and Ireland) ought to be more thoroughly investigated than they have been. The colour of such sands varies from pale

grey and brown to deeper tints, and usually darkens considerably on burning. Too much iron is present, and the heavy mineral-crop is frequently large. Commercial electromagnetic separation will hardly clean the sands sufficiently. They are of little use except for "black" glass-work when the industry is located close at hand.

The purest shore-sand met with is that occurring on the western shores of the **Isle of Jura,** and derived from the Dalradian quartzites forming the greater part of the island. This sand is said to have been formerly worked for glass, but it is of limited extent and, although very white-looking, contains 0·07 per cent. of iron oxide.

The beach-sand from the **Isle of Eigg** is also of fairly good quality, and consists of very clean and colourless angular quartz, mixed with a considerable quantity of dark kaolinized felspar, but it yields a large crop of heavy minerals derived from neighbouring igneous masses (augite, olivine, epidote, garnet, zircon, etc.).

Similar sands from near Dublin (**Sandymount Strand**) have been used in the dark-bottle industry of that city.

Additional shore- and dune-sands from Ireland have also been examined in view of the needs of the bottle-industry *. Samples of blown sands from **Sutton (Kilbarrick)** near Dublin, **Washing Bay, Coalisland** (on Lough Neagh), **Ballycastle** (Co. Antrim), etc., have been examined and analysed, with the results given on page 165.

G. H. Kinahan. in his account of the economic geology of Ireland †, mentions the occurrence at Ballycastle of a white sand suitable for glass-making, stating that it occurs as Drift. It lies upon and is presumably derived, at any rate in part, from the Carboniferous Sandstone. The sand worked for the old Ballycastle Glass-works (up to 1820) was blown-sand from the dunes, not a very pure material, and the glass made was a rough thick green bottle-glass only.

Specimens of a shore-sand from **Maghera, Ardara,** Co. Donegal, have been forwarded by the Officer in Charge of the Coastguard Station, who says that the quantity available is unlimited. The sand is unfortunately somewhat shelly and rich in heavy detrital minerals. The iron-percentage (Fe_2O_3) is 0·7 per cent. A similar but slightly less pure sand has been obtained from **Sandfields,** Ardara. Mechanical analyses of these sands will be found in the Tables.

Besides those sands analyses of which are given later (see pages 157, 165), samples from the following localities (sent by the courtesy of Sir Bertram Windle, F.R.S., President of University

* Prof. Gilbert Morgan issued a report on Irish Glass-sands shortly after the outbreak of war. This statement mentioned, besides Muckish Mountain Sand, deposits which might be worked for bottle-making, and which occurred at Sutton near Dublin, Rosslare, Silver Strand (Wicklow), Ardara (Co. Donegal), and Washing Bay (Lough Neagh).

† Journal Royal Geol. Soc. Ireland, vol. viii. (1887).

College, Cork), have been examined:—**Castlefreke** (Cork), **Claycastle** (Youghal), **Glenbeigh** (Kerry), **Kilkee** (Kerry), and **Rushmere** (Tramore).

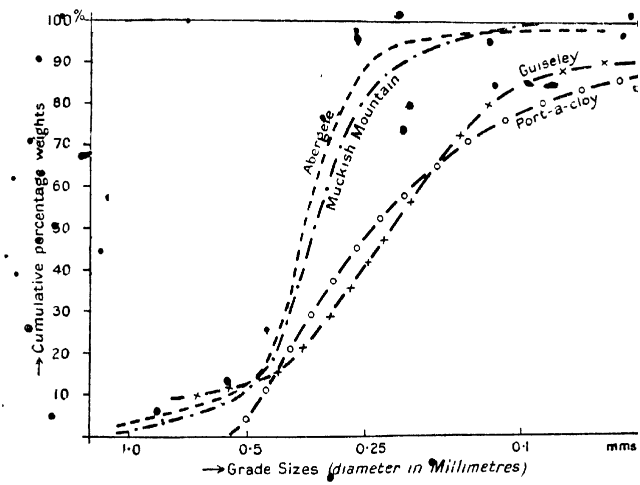
Information regarding other sands investigated will be found in the Tables or, incidentally, in the remarks below. Sandstones and quartzites naturally disintegrated or crushed to produce "glass-sands" are discussed in Chapter VII.

CHAPTER VII.

A. PURELY SILICEOUS DEPOSITS (*continued*).
(*b*) CRUSHED ROCKS.

Many crushed quartzose rocks have been placed upon the market as proposed substitutes for glass-sands. At the outset, it may be said that they have never found much favour with British

Fig. 12.—*Mechanical Analyses of Glass-Sands: Crushed Rocks, etc.*



manufacturers, although such materials appear to be extensively used abroad. The great evil of rock-crushing lies in the quantity of dust, which is waste material, produced. Mining engineers are still endeavouring to devise a machine that will grind or crush rocks to a fine even grade without producing slime. So far as glass-making materials go, the remarks regarding the unsuitability of sand not of even grade apply still more emphatically here. Several pure sandstones and quartzites, of various geological ages from pre-Cambrian to Coal Measures, occur in the British Isles, and a few have been crushed and exploited. Mechanical analyses of the products are given in the Tables. Sifting is usually carried out at the quarries, and so those coarse grades which are objectionable are eliminated. Large quantities of fine grades and

dust are, however, produced, and, in order to yield an effective sand, these ought to be washed away with water-currents of strength calculated as above from elutriation data. It is frequently necessary to remove electromagnetically the iron particles derived from the crushing-plant. The cost of quarrying, crushing, and sifting has generally been too great to permit of washing also, and the price of the unwashed material is often prohibitively high, even in the neighbourhood where it is produced. Much more is the cost increased by the usual heavy freights, so that there is little likelihood of such materials replacing glass-sands to any extent for ordinary work in this country. High content of silica, and alumina also if that is desired, low iron, and general purity and angularity are their chief recommendations. Difficulties occur in the use of these crushed rocks. Often it does not pay to wash them, and consequently loss results from the burning out of the fine grade, and unevenness in the "metal" is caused by irregular melting. The fine material carries with it air-bubbles, from which the "metal" is cleared with great difficulty. As in the case of crushed quartz-crystals themselves, it is also objected by many glass-manufacturers that the "metal" produced from the crushed material tends to be "cordy" or "wavy" and to remain "sticky" too long upon cooling, which also takes a longer time than is desirable. Whether this is the result of the mixture of fine grades, of the presence of two allotropic low temperature forms of quartz, differing crystallographically, one possibly as a cement, of the different hydration of the silica acting as matrix, or of the presence of certain inclusions in the quartz, is not known. Greater heat, or more prolonged melting of the batch, appears to be required when crushed rocks are used *. It is noteworthy that the sand obtained from Muckish Mountain, Co. Donegal, Ireland, is a naturally disintegrated pure pre-Cambrian quartzite. It is often difficult to draw the line between a true sand and such a disintegrated sandstone or quartzite. The mechanical analyses on page 82 indicate, however, that it has been well-graded, probably a result of percolating waters for a long period, helped by the fact that the original sandstone was also well-graded, and most of the cement has since been removed. It contains rather too much coarse material, but this is very friable, and can be rubbed down in the fingers, compound-grains thus breaking up. The analyses (see also Fig. 12) should be compared with those of Guiseley material (which was supplied sifted to 40-mesh), Port-a-cloy Silica, Westport Silica, etc. Even after washing and sifting, the residual rock-particles are distributed over several grades and the mixture is still unsatisfactory.

Among decomposed or crushed sandstones and quartzites examined were the following:—

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* On the behaviour of the forms of silica, see Fenner, Amer. Journ. Science, vol. 36 (1913) p. 331, and Journ. Wash. Acad. Sc. vol. 2 (1912) p. 471; Wright & Larsen, Amer. Journ. Science, vol. 27 (1909) p. 421, and others.

§ **Muckish Mountain Sand, Co. Donegal.**

Worked by Messrs. Arkwright & Rapaport, 22 Bank Buildings, Kingsway, W.C. 2.

Maps.—Geological: Old Series (Ireland), 1-inch, Sheet 10.
6-inch, Donegal, Sheet 34.

Situation.—*Lat.* 55° 6′ 20″, *Long.* 7° 59′ 50″ W.

The sand lies on the top and upper slopes of a hill (Muckish Mountain) of quartzite about four miles from the sea, and about thirty-three miles east of north of Donegal. It consists of scree material resulting from the decomposition of the quartzite.

Formation.—Pre-Cambrian (Dalradian).

Description.—Trial-workings are being carried out to ascertain the extent of the sand. Many pits and trenches, including one driven twenty feet into the hillside, have now been made, and a considerable area of rock cleared of grass, peat, and rubble. The amount of sand still appears to be small, but the excavations have proved the existence of several beds of considerable extent, consisting of soft white sandstone—a result of the partial disintegration of the quartzite. All the chemical analyses of Muckish Mountain material reveal the presence of a small quantity of lime (CaO), so that it is possible that the sandstone was once calcareous, perhaps bearing a calcareous cement, and that the calcium carbonate has been leached out as a result of the weathering agencies and acid peaty waters. The rock is seen in all stages of decomposition, from hard flinty quartzite to a friable sandstone which can be broken up in the fingers. The quantity of actual unconsolidated sand present is very limited.

As the seams of soft rock occur immediately below the flat top of the mountain, over two thousand feet above sea-level, it is probable that much of the soft rock will be reduced to sand in the process of running it down the shoots to the foot. However, a certain amount of the material will not be broken up in this way and will require crushing. (See Plate IV. figs. 3 & 4, which show the manner of cementation of the grains.) Owing to the softness of the cement, this will not be a difficult or expensive matter. Screening is also necessitated, since the crushed and decomposed products contain coarse compound grains which remain as "stones" in the glass made from the rock. Washing is desirable to assist the grading by clearing the sand of fine dusty silica, etc., and to reduce the iron-content of the browner varieties. The available water-supply is small, especially in the summer.

The chemical analyses of some samples of the rock recently collected are as follows:—

Bulk sample, mixed from all the trenches.	
SiO_2	99·55 per cent.
Al_2O_3	0·17
Fe_2O_3	0·02
CaO	0·20
MgO	trace
Loss on ignition	0·16
Total	100·10 per cent.

Iron-content.	
Trench 1	0·028 per cent.
„ 2	0·022
„ 3	0·009

The brown colour of many specimens is due to staining by peaty waters and is not detrimental. One such brown variety contained only 0·029 per cent. of iron oxide (Fe_2O_3).

Mechanical analyses of the same samples are as follows:—

	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sd.-gr.: >0·1 mm.
Trench 1	...	2·5 %	72·8 %	19·9 %	3·0 %	1·8 %	95·2 %
" 2	2·0 %	14·7	73·9	7·9	0·5	1·0	98·5
" 2 a	.	9·8*	73·1	15·8	0·8	0·5	98·7
" 3	2·5	13·6	75·4	7·5	1·0	0·0	99·0
A fine seam	..	0·3*	36·7	58·3	3·2	1·5	95·3

* Compound grains.

The rock contains a very small proportion of heavy detrital minerals, little else but zircon being present. The sand was used by the Irish Department of Agriculture in the reproduction of Waterford Glass for the Cork Exhibition in 1902. Good glass has also been made from it in the London, Birmingham, and Yorkshire areas.

The price at which this material is to be supplied has not yet been fixed. Should it not be low enough to enable the sand to replace foreign supplies in England, we may still be assured, in the Muckish Mountain deposit, of a large supply of material of excellent quality, sufficiently good for the making of the best optical glass.

The nearest port is Ballyness, six miles from the foot of the hill. The Donegal Railway runs about a mile from the foot, and the port of Dunfanaghy is six miles distant.

§ Crushed Sandstone from Guiseley, near Leeds.

Worked by The Guiseley Ganister Company.

Maps.—Geological: Old Series, 1-inch, Sheet 92 S.E.
6-inch, Yorkshire, Sheet 202 N.W.

Situation.—*Lat.* 53° 52′ 5″, *Long.* 1° 44′ W.

The quarry lies one mile west-south-west of Guiseley.

Formation.—Coal Measures.

Description.—The purity and high silica-content of certain sandstones of Coal Measure age are well-known and the rocks on that account are prized. The Guiseley rock is much shattered, and is washed at the quarries, being supplied at present to the steel industry. It is proposed to crush and sift the rock for glass-making. The sifted product is free from coarse grains, but naturally is spaced over several grades, and contains objectionable fine material. The cost of washing, to rid the sand of the latter, is somewhat prohibitive, the price without washing varying from 15*s.* to 17*s.* per ton even in the neighbouring Yorkshire glass-making area. However,

certain glass-manufacturers are trying the sand. It is white, bears only a small quantity of iron, and does not darken on burning. The chemical analysis of the crushed rock is as follows:—

SiO_2	97·45 per cent.
Al_2O_3	1·76
Fe_2O_3	0·09
CaO	0·13
MgO	trace
Loss on ignition	0·78
Total	100·21 per cent.

An uncrushed sample of rock yields the following analysis:—

SiO_2	98·93 per cent.
Al_2O_3	0·60
Fe_2O_3	0·03
CaO	0·24
MgO	none
Loss on ignition	0·29
Total	100·09 per cent.

The greater amount of iron in the crushed sample is therefore presumably due to additional impurity obtained from the crushers.

The mechanical composition, after sifting to 40-mesh, is:—

$>0·5$ & <1 mm., 0·1 %; $>0·25$ & $<0·5$, 40·1 %; $>0·1$ & $<0·25$, 44·3 %; $>0·01$ & $<0·1$, 9·2 %; $<0·01$ mm., 6·3 %. Total sandade, $>0·1$ mm., 84·5 %.

$$\left[\frac{CS}{0·1}, \frac{MS}{40·1}, \frac{FS}{44·3}, \frac{s}{9·2}, \frac{c}{6·3}; \frac{S}{84·5}\right]$$

The mineral composition indicates the presence of very rare felspar, a colourless flake of garnet (?), anatase growing on ilmenite, abundant small red-brown rutile, zircon, limonite, leucoxene, etc.

§ Sandstone from Mold, Flintshire.

Worked by The Mineral Milling Company, Mold.

Maps.—1-inch Geological, Sheet 79 S.E.
6-inch Flintshire, Sheet 13 N.W.

Situation.—*Lat.* 53° 10′ 20″, *Long.* 3° 11′ 12″ W.

The mine occurs at Waen, immediately north of the Smithy, one hundred and fifty yards north of Trinity Church and about two miles west of Mold.

Formation.—Carboniferous Limestone.

Description.—The bed of white sandstone is about twenty-three feet thick and occurs below a bed of Carboniferous Limestone, which in the shaft is about twenty-two feet thick. Impure limestone also occurs below the sandstone. At present the rock is

mined and brought up the shaft, but a drift is being run eastwards from the surface down to the working. The sandstone is of good colour with little or no iron-staining. It is constant in quality and grade, and is soft and easily crushed. After ignition, the colour remains unchanged. The unwashed product contains only 0·024 per cent. of iron oxide. The washed product has the following chemical composition :—

SiO_2	98·97 per cent.
Al_2O_3	0·46
TiO_2	0·04
Fe_2O_3	0·02
CaO	0·10
MgO	0·07
K_2O	0·08
Na_2O	none
Loss on ignition	0·34
Total	100·08 per cent.

The crushed material is fairly well-graded, as the following result of a mechanical analysis indicates :—

>0·5 mm. & <1 mm., 9·2 % ; >0·25 & <0·5, 78·1 % ; >0·1 & <0·25, 10·5 % ; >0·01 & <0·1, 0·9 % ; <0·01, 1·3 %. Total sand-grade, >0·1 mm., 97·8 %.

$$\left[\frac{CS}{9{\cdot}2},\ \frac{MS}{78{\cdot}1},\ \frac{FS}{10{\cdot}5},\ \frac{s}{0{\cdot}9},\ \frac{c}{1{\cdot}3};\ \frac{S}{97{\cdot}8}\right]$$

Washing improves it by removing the fine dusty material.

The heavy detrital minerals form a very small percentage of the whole (0·01 per cent.). The assemblage includes only the stable commonly-occurring detrital minerals, such as magnetite in well-shaped crystals, ilmenite altering to leucoxene, and with crystals of anatase growing upon it, tourmaline in bluish, greenish, and brown grains (all 0·1 to 0·2 mm. diameter), together with tiny zircons and rutiles (0·05 mm. diameter). The sandstone also contains decomposed felspar.

The material is utilized in the manufacture of abrasive soaps, but should also be of much value for glass-manufacture and for refractory purposes.

Two miles of good road connect the mines to Mold Station (L. & N. W. Railway), where it is put uncrushed F.O.R. at 17*s*. 6*d*. per ton. The crushed product can be similarly supplied at about 20*s*. to 22*s*. per ton.

The available resources are over ten million tons.

The deposits of sandstone at **Pant du** and **Minera** are similar in character to that described above, but are on the whole less pure. The highly siliceous "sand" from **Mow Cop** in Cheshire is of the same character and is worked for pottery purposes (see pages 155 and 161).

The pulverized material obtained from the cutting and dressing of sandstones of Millstone Grit age at **Rowsley**, in Derbyshire, is used for the making of common bottle-glass in Derby.

§ "**Spital Sand.**"

Worked by Mr. H. A. Walker, 13 Imperial Buildings, Exchange Street East, Liverpool.

Maps.—Geological: Old Series, 1-inch, Sheet 79 N.E.
6-inch, Cheshire, Sheet 13 S.E.

Situation.—*Lat.* 53° 21′ 5′, *Long.* 3° 1′ 45″ W.

The quarry is situated at Higher Bebington, near Spital, half a mile south-south-west of the Church, and over one mile west-south-west of Bebington Railway Station.

Formation.—Keuper Waterstones.

Description.—About thirty to forty feet of creamy-white, soft sandstone are exposed in a large quarry, showing strong faulting on the western side. Like many of the Keuper deposits, the sandstone is felspathic, much of the orthoclase felspar having decomposed to kaolin-like material. The sandstone, which is easily crushed, therefore yields a poorly-graded deposit. Washing would effect a considerable improvement in the sand, so far as glass-making is concerned.

In its present state it is used for making pale bottles (Dublin, Belfast, etc.), and as a refractory material in the iron, steel, and copper industries.

Although the grains are coated in part with white clayey matter, the sand, which is about equal in colour to that of Lynn, darkens on burning. The chemical composition is as follows:—

SiO_2	94·60 per cent.
Al_2O_3	2·99
Fe_2O_3	0·06
CaO	0·20
MgO	0·14
K_2O	1·44
Na_2O	none
Loss on ignition	0·65
Total	100·08 per cent.

Another sample, after being washed, showed an iron-content of 0·09 per cent.

Although the clayey matter is objectionable, there is little doubt that the alumina present strengthens considerably the bottle-glass made from the sand.

The mechanical analysis is as follows:—

>0·5 & <1 mm., 0·7%; >0·25 & <0·5, 81·7%; >0·1 & <0·25, 13·6%; >0·01 & <0·1, 1·4%; <0·01, 2·6%. Total sand-grade, > 0·1 mm., 96·0%.

$$\left[\frac{CS}{0{\cdot}7}, \frac{MS}{81{\cdot}7}, \frac{FS}{13{\cdot}6}, \frac{s}{1{\cdot}4}, \frac{c}{2{\cdot}6}; \frac{S}{96{\cdot}0}\right]$$

The microscopic examination of the rock indicates that the heavy minerals are remarkably well-rounded, but that the variety among the commonly-occurring minerals is not great. A little magnetite is found, but ilmenite (0·2 mm. in diameter) is much more abundant. Yellow-brown, highly rounded grains of tourmaline are very plentiful (0·2 to 0·3 mm.), and characteristic deep blue and purplish grains occur. Tiny zircons and rutiles (0·1 mm.), and yellow to colourless anatase crystals (0·1 mm.) also are seen. The heavy detrital residue amounts to 0·06 per cent.

The crushing strength, tested on 3-inch cubes (average of four tests) is 1450 lbs. per square inch.

The price is 7s. 6d. per ton F. O. R. at Spital Station (L. & N.W. & G.W. Joint Railway), and 9s. 6d. F.O.B. at Birkenhead.

The available resources are over twenty million tons.

§ Sand from Caldwell, N.B.

Worked by The Caldwell Sand Company Ltd., per Mr. Wm. F. Pirrit, 50 Renfield St., Glasgow.

Maps.—Geological, 1-inch, Sheet 22.
6-inch, Renfrewshire, Sheets 15 N.E. and 16 N.W.

Situation.—*Lat.* 55° 46′ 15″, *Long.* 4° 29′ 0″ to 20″ W.

Several quarries occur on the south-east side of the Barrhead Road, nearly a mile north-east of Caldwell Station (Glasgow & South Western Railway). The quarry at present being worked is the most westerly of them.

Formation.—Carboniferous Limestone Series.

Description.—The quarry exhibits about twenty to thirty feet of soft decomposed sandstone of variable colour, from cream to red-brown. The strata dip north-westwards towards the road, and shale is revealed in the bottom of the quarry, underlying the sandstone. Pebbly seams occur, and in parts the sandstone is coarse and not well-graded.

On ignition the sand darkens slightly to a brown tint. The chemical analysis of an unwashed sample of the best material available for glass-making is as follows:—

SiO_2 ..	93·74 per cent.
Al_2O_3	4·11
Fe_2O_3	0·04
CaO	0·27
MgO	0·12
K_2O	0·46
Na_2O	0·03
Loss on ignition	1·37
Total	100·14 per cent.

Another washed and screened sample contained 0·08 per cent. of iron oxide.

The mechanical analyses of washed and unwashed samples (collected at different times) are as follows:—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade: >0·1 mm.
Unwashed	5·5 %	82·9 %	5·8 %	1·1 %	4·7 %	94·2 %
Washed	21·0	69·4	8·9	0·5	0·2	99·3

The mineral analysis indicates the abundance of large pink and colourless garnets (0·5 mm. diameter) with good crystal form, muscovite flakes (0·4 mm.), grey tourmaline (0·1 mm.), limonite, ilmenite, abundant zircon and red rutile, and, rarely, epidote. The heavy mineral crop constitutes 0·08 per cent. of the sand.

The material is crushed in a pan-mill, washed in rotary apparatus, and screened before being supplied to the Glasgow steel-area. Some of the other quarries were formerly worked for glass-sand, but at present the output is taken entirely for refractory purposes.

The prepared material costs 10*s.* per ton F.O.R. at Caldwell Station (Glasgow & South Western Railway).

The available resources are over two million tons.

§ Sand from Kilwinning, N.B.

Not at present being worked.

Maps.—Geological, 1-inch, Sheet 22.

6-inch, Ayrshire, Sheet 11 S.E.

Situation.—Lat. 55° 39′ 33″, *Long.* 4° 44′ 45″ W.

The outcrops of white sandstone occur close to the south-western nd of Ashgrove Loch, near to Lochcraigs Farm, about a mile and a alf west-north-west of Kilwinning Station. A less pure sandstone f slightly different age crops out by the roadside near Bankend 'arm, north-east of the Loch.

Formation.—Carboniferous Limestone Series.

Description.—A considerable area of rough ground and crags verlooking the southern end of the Loch is occupied by the utcrop of a bed of white sandstone which is apparently over wenty feet thick. The sandstone is white and breaks down easily n the fingers. It looks decidedly promising for glass-making and efractory purposes, and after being washed yields a well-graded nd pure sand, which becomes greyer on ignition.

The chemical composition of an unwashed sample is as follows :—

SiO_2	98·85 per cent.
Al_2O_3	0·53
TiO_2	0·06
Fe_2O_3	0·02
CaO	0·11
MgO	0·06
K_2O	trace
Na_2O	none
Loss on ignition	0·38
Total ……	100·01 per cent.

The iron-content of another washed sample is 0·028 per cent.

Some of the material is fine in grain and rather well-graded (*sample b*). *Other samples collected were much coarser.* Mechanical analyses are as follows:—

	VCS. ·1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	S. >0·01 & <0·1.	C. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed (*a*) .	13·5 %	30·0 %	54·6 %	1·1 %	0·2 %	0·6 %	99·2 %
Washed (*b*)		0·5	92·5	5·5	0·5	1·0	93·5

[(*a*) and (*b*) were different samples of sand.]

A mineralogical analysis shows the presence of ilmenite and leucoxene, limonite, muscovite (flakes 0·5 mm. diameter), brown tourmaline (0·3 mm.), sillimanite, red rutile, and zircon (0·1 mm.) among the heavy crop of minerals, which amounts to 0·02 per cent. of the whole. The heavy residue of the sample examined was rather coarse in grain.

Difficulties may arise over transport. The nearest station is Kilwinning, but to reach it half a mile of rough farm-track and a quarter of a mile of fairly good road have to be traversed.

The available resources appear to be not less than half a million tons.

§ Sand from Levenseat, N.B.

Worked by Messrs. J. & T. Thornton, Levenseat Quarries.

Maps.—Geological: 1-inch, Sheet 31.

6-inch, Edinburgh, Sheet 10 S.E.

Situation.—*Lat.* 55° 48′ 30″ to 45″, *Long.* 3° 41′ 40″ W.

The sandstone is being worked in several quarries, about one and a half miles east-south-east to south-east of Fauldhouse Station, and one mile south-east of Crofthead Station (Caledonian Railway). The chief quarry is the most southerly and lies on higher ground about three-quarters of a mile south of Levenseat Hamlet.

Formation.—Millstone Grit.

Description.—The best face of sandstone is that revealed in the quarry on the higher ground, where a thirty-foot wall of the deposit, practically free from overburden, is to be seen. In the lower quarries several feet of Drift occur above the bed, and shale is met with about four feet below the floor of the pit. In all, the workable sandstone bed is probably about eighty feet thick and covers a wide area. The stone, yellowish to brown in colour, has decomposed until it breaks down readily into sand when rubbed in the fingers or on being dropped into water. On ignition it darkens to a red-brown tint. Much of the yellow or brown staining washes away freely from the grains of quartz, clayey matter is removed from

the decomposed felspar, and a well-graded cream-coloured sand is yielded. On ignition the washed product becomes slightly darker.

The chemical analysis of a washed sample is as follows:—

SiO_2	99·46 per cent.
Al_2O_3	0·16
TiO_2	0·04
Fe_2O_3	0·03
CaO	0·13
MgO	none
K_2O	none
Na_2O	none
Loss on ignition	0·19
Total	100·01 per cent

Before being washed, a sample of the sand was found to contain 0·07 per cent. of ferric oxide.

The result of washing is also to improve the grading very considerably—indeed, a well-graded material is produced.—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed	3·7 %	88·5 %	6·0 %	0·2 %	1·6 %	98·2 %
Washed	a few grains.	94·3	5·5	0·1	0·1	99·8

The mineral composition of the sand calls for little note and the heavy crop amounts to only 0·09 per cent. The most commonly occurring heavy detrital minerals are ilmenite altering to leucoxene, zircon, rutile, and brown and grey tourmaline. The heavy residue is fine-grained, the average diameter being 0·1 mm.

In its unwashed state, the sandstone, after having been crushed in a pan-mill and screened, is sent to the Edinburgh district for the making of green bottles, floats, etc. The alumina present adds considerably to the tensile strength of the glass. Arrangements have now been made, it is satisfactory to add, by Mr. Hugh Reid of Motherwell, to wash the sand in tank-washers. The washed product should be of high quality, and, as the above analysis indicates, of great value in the steel industry for furnace purposes.

The unwashed crushed material is put F.O.R. at Crofthead Station at 9*s*. a ton.

The available resources are probably over fifteen million tons.

Other Carboniferous Sandstones of the Midland Valley of Scotland have been worked extensively for building-stone. Among these are the rocks from **Cowie** and **Plean**, two localities near Stirling, **Kingscavil**, near Linlithgow, **Glenboig**, and **Hailes** near

Edinburgh. Most of these are soft greyish-white or pale brown sandstones, with occasional carbonaceous layers.

The sandstone of Corallian age which is associated with coal and oil-shale ("parrot") at **Brora** is greyish-white, and is fine and regular in grain. The best exposure is in Clyneleish Quarry, half a mile north-west of Brora, but although the rock is fairly soft, it could not be crushed and transported to a glass-making area at other than a prohibitive price. A certain amount of sand, the result of decomposition of the rock, is also to be found. The material is not pure enough for the making of good glass-ware, the iron-content (as Fe_2O_3) being 0·12 per cent., but it might serve for refractory purposes.

§ Sand from Ballycastle, Co. Antrim.

Not at present being worked: Ballycastle Estate; Agent, Capt. S. J. Lyle, M.C.

Maps.—1-inch Geological, Sheet 8.
6-inch, Co Antrim, Sheet 5.

Situation.—*Lat.* 55° 12' 50'', *Long.* 6° 11' to 6° 13' W.

The exposures of cream-coloured sandstone occur in the cliff-sections, east of Ballycastle, from White Mine to Gobb, a distance of about a mile.

Formation.—Lower Carboniferous Sandstone.

Description.—About sixty feet of whitish sandstone occur above the Main Coal of the Ballycastle Coalfield. In the upper portion shale bands occur, and the best sandstone material is the "post" which forms the roof of the Main Coal. The sandstone crops out along the shore and is visible in the cliffs at White Mine, where it is seemingly purest and best-graded, Griffin Mine, Gobb, and other places. Much lateral variation in particular sandstone beds is to be observed. The Main Coal is at present worked by Messrs. Heckie, Aiton & Kerr (Ballycastle Colliery). In view of the proximity of fuel, availability of machinery, and abundant water-supply, it should be possible to work and treat this sandstone economically. The rock is soft and easily crushed. It would also need washing and screening.

The sand, which is cream-coloured, becomes browner after ignition. The chemical composition is as follows:—

SiO_2	98·57 per cent.
Al_2O_3	0·52
TiO_2	0·05
Fe_2O_3	0·02
CaO	0·20
MgO	0·05
K_2O	0·06
Na_2O	0·05
Loss on ignition	0·42
Total	99·94 per cent.

The mechanical composition of a crushed sample is:—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed	3·3 %	82·8 %	12·0 %	1·1 %	0·8 %	98·1
Washed	5·3	87·3	6·5	0·6	0·3	99·1

In mineral composition, the sandstone resembles other Coal-Measure Sandstones of the north of Ireland. The heavy residue, forming 0·03 per cent. of the sand, is coarse in grain, and consists chiefly of the stable and common minerals, zircon, rutile, limonite (all about 0·2 mm. in diameter), muscovite (0·4 mm.), and anatase.

The railway facilities are not good (the Ballycastle Railway links Ballycastle to Ballymoney on the Midland, N. C. I., Railway), but a pier and a jetty are also close at hand.

Messrs. Heckie, Aiton & Kerr propose to work the deposit at White Mine, and the British Silica & Minerals Company Ltd. that at Gobb. The material, being a high-silica sand, is of value as a refractory material (for furnace-linings, etc.) as well as glass-making.

The available resources are undoubtedly large

§ Sand from Cookstown, Co. Tyrone.

Worked by Richard Cluff, Esq., Kildress House, Cookstown.

Maps.—1-inch Geological, Sheet 26.

6-inch, Co. Tyrone, Sheet 29.

Situation.—*Lat.* 54° 38′ 40″, *Long.* 6° 47′ 0″ W.

The pit is situated in the townland of Lower Kildress about half a mile east of Kildress House.

Formation.—Calciferous Sandstone (Upper Group).

Description.—About thirty feet of soft sandstones are exposed in the pit which is by the side of the small stream known as the Ballinderry River. The upper portion is stained red and brown, in part as a result of the percolation of peaty waters and in part by oxide of iron. Ferruginous bands, often wedge-shaped, also occur lower down, but the iron oxide is not present in large quantity, and washing frees the quartz-grains easily from the pink pellicles. Some six or seven feet of pure white sandstones are seen. The sandstone is thoroughly decomposed and washing in water serves to disintegrate it. Screening, however, must be adopted to free the product from quartz-pebbles and harder sandstone pellets.

The red sands darken in colour on ignition, and the cream-coloured sand becomes greyer.

The chemical composition is as follows:—

SiO_2	96·97 per cent.
Al_2O_3	1·61
Fe_2O_3	0·04
CaO	0·20
MgO	0·11
K_2O	0·15
Na_2O	0·03
Loss on ignition	0·72
Total	99·83 per cent.

The iron-content of a washed sample of red sand is 0·04 per cent., and of the cream-coloured sand, 0·02 per cent.

Much clayey material (kaolin) is present—a result of the decomposition of felspar. After being washed, the sand is well-graded, as the following mechanical analyses indicate:—

	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	S. >0·01 & <0·1.	C. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed.	1·8 %	9·7 %	80·6 %	4·2 %	0·3 %	3·4 %	96·3 %
Washed	2·0	8·1	79·0	10·1	0·3	0·5	99·2

The heavy mineral residue (0·03 per cent.) is fine in grain and consists mainly of zircons (0·05 mm. diameter). Other minerals noted were yellow rutile, anatase growing on ilmenite, and brown and blue tourmaline.

At the present time the mixed and unwashed sand is sold for bottle-making in Belfast at about 20*s*. per ton, which represents a cost of 14*s*. 6*d*. per ton at Cookstown Station. From the quarry to the station three miles of road-transport are necessary. If the white sandstone were washed and screened, the material would serve for the making of glass of much better quality. Water-power and an abundant water-supply are available.

The resources are difficult to estimate, but are considerable. The liability of the rocks to vary laterally introduces difficulty in computation.

Sand from Coolkeeragh, Londonderry.

On the eastern side of the Foyle, and north-east of Coolkeeragh House, five miles north of Londonderry, a small excavation has been opened by Mr. John Burns, the owner of the estate. Soft white and pale-reddish sandstones are visible, apparently of about the same age and very similar in appearance to those at Cookstown, etc. (Upper Calciferous Sandstone). The same rock occurs also at White Castle on the shores of the Foyle, but is much less accessible.

The Coolkeeragh rock breaks down very easily, disintegrating when placed in water. In its present state it serves for bottle-making, but if washed and screened would be useful for better-class glass-making. On ignition it becomes greyer, and the chemical composition of an unwashed sample is as follows:—

SiO_2	84·96 per cent
Al_2O_3	8·59
TiO_2	0·18
Fe_2O_3	0·18
CaO	0·34
MgO	0·31
K_2O	4·54
Na_2O	0·08
Loss on ignition	1·54
Total	100·72 per cent.

Another sample collected by the writer contained 0·13 per cent. of ferric oxide, while the content of a washed sample was 0·075 per cent.

Washing removes also the kaolin yielded by the decomposing felspar, and results in the production of a well-graded sand, as the following mechanical analyses indicate:—

	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.
Unwashed	. ..	7·1 %	75·9 %	7·5 %	3·0 %	6·5 %	90·5 %
Washed ..	1·1 %	2·7	90·4	4·6	0·5	0·7	98·8

The mineral assemblage is like that of other sandstones of similar age in northern Ireland (Cookstown, Ballycastle, etc.), the commonly-occurring heavy minerals (which form 0·05 per cent. of the sand) being muscovite and chlorite (flakes 0·6 mm. diameter), brown tourmaline, small irregular and angular garnets (0·1 mm.), small zircons and rutiles, leucoxene, and plentiful anatase, in yellow tablets or growing upon ilmenite.

The deposit is favourably situated for transport. The Midland Railway (Londonderry to Coleraine and Belfast) is only a few yards distant, and the deposit is close to the River Foyle.

Further exploration is desirable before the resources can be estimated.

"Port-a-cloy Silica."

This material is apparently a decomposed or crushed quartz-mica schist (Dalradian), and is to be worked by the China-Clay, Felspar,

& Silica Company Ltd. It is found near Stonefield on Port-a-cloy Bay, Co. Mayo. (*Lat.* 54° 19′ 50″, *Long.* 9° 47′ 0″ W. Geological Map, 1-inch, Sheet 40.)

A chemical analysis carried out by Dr. H. F. Harwood yields the following result:—

SiO_2	76·47 per cent.
Al_2O_3	12·66
TiO_2	0·31
Fe_2O_3	1·82
CaO	0·12
MgO	0·45
K_2O	5·05
Na_2O	0·31
Loss on ignition	2·94
Total	100·13 per cent.

With this should be compared the analysis of another sample by Mr. J. H. Davidson, M.Sc., of the Department of Glass Technology in the University of Sheffield:—

SiO_2	75·00 per cent.
Al_2O_3	14·83
TiO_2	1·09
Fe_2O_3	1·02
CaO	trace
MgO	0·44
Alkalies as sulphate	3·54
Loss on ignition	3·97
Total	99·89 per cent.

In each case the iron and titanium are high, and, being elements which militate against the making of good glass, should be removed. The titanium is present as crystals of rutile, some of which in the uncrushed rock are of considerable size. The extraction of the mineral is a difficult problem. Washing and electromagnetic treatment may possibly improve the iron-content.

Samples of washed material yield the following result:—

(B) Fe_2O_3	0·09 per cent.	(C) SiO_2	80·48 per cent.
		Al_2O_3	11·57
		Fe_2O_3	0·23
		Loss on ignition.	3·25
		Total	95·53 (partial analysis only).

The sand is grey in colour and darkens on heating. The material is poorly graded, mechanical analyses of some samples being as follows:—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	>0·01 & <0·1.	C. <0·01 mm.	S. Total sand-grade >0·1 mm.
(*a*) Untreated	2·6 %	55·6 %	29·8 %	8·1 %	3·9 %	88·0 %
(*b*) Washed		49·7	44·7	4·5	1·1	94·4
(*c*) Mixture		34·2	46·0	9·0	10·8	80·2

(*a*) was an untreated sample, (*b*) was a washed sample treated for iron oxide, and coarse-screened, (*c*) was a sample produced by mixing (*b*) with "silica and alumina" washed out of (*a*), to make about 8 per cent. of alumina

In mineral composition, the sand consists almost entirely of quartz and muscovite mica (flakes 0·5 mm. diameter), with some rutile (0·05 mm.), chlorite (0·2 mm.), ilmenite and zircon.

§ The **Stiper Quartzite**, at the base of the Ordovician system, is worked on a large scale for road-metal, filtration, and refractory purposes, in the Granham's Moor Quarries near **Pontesbury, Shropshire**. (*Lat.* 52° 37′ 40″, *Long.* 2° 54′ 0″ W.; 6-inch map, Sheet 40 S.W.)

The quartzite is reduced to small fragments by jaw-crushers, but so far as the writer is aware, has not been tried for glass-making. The crushing strength is 32,000 lbs. per square inch (see page 129). The rock is much shattered and iron-stained in places. An average sample of the pure white rock yielded the following chemical analysis:—

SiO_2	96·47 per cent.
Al_2O_3	2·24
Fe_2O_3	0·06
CaO	0·21
MgO	0·12
K_2O	0·58
Na_2O	none
Loss on ignition	0·59
Total	100·27 per cent.

The alumina and potash percentages are explained by the presence of numerous grains of felspar in the rock.

The price of the stone, ground to pass any mesh up to 100 per linear inch, is approximately £5 per ton F.O.R. at Pontesbury Station (L. & N. W. & G. W. Railways). All grades of grit, after being washed, are similarly supplied at prices varying from 12*s.* 6*d.* to 37*s.* 6*d.* per ton.

§ The quartzite of pre-Cambrian age (Dalradian) occurring in the **Appin** Quartzite Quarries near **Kentallen**, Argyllshire (owner, Lt.-Col. W. Macalpine Downie), is worked for acid-filtration, grinding, and refractory purposes, but has not yet been utilized for glass-manufacture. It is very hard and compact, and on the whole of good quality (see chemical analysis in Table on page 155). The crushing strength is 32,200 lbs. per square inch (see page 129).

Similar quartzites occur in **Islay** and **Jura**.

§ A compact and good quality quartzite is worked by Messrs. Wm. Wild & Sons in extensive quarries on **Holyhead Mountain, Anglesey.** It is crushed and used for the making of silica-bricks, and for "gannister" for lining Bessemer converters, etc. In places it is very pure, but joint-planes stained with ferruginous matter spoil it for use in glass-making. The quartzite is of pre-Cambrian age and frequently exhibits a foliated structure. It is traversed by abundant quartz-veins. The chemical composition of a typical sample of rock is as follows:—

SiO_2	99·32 per cent.
Al_2O_3	0·19
TiO	0·03
Fe_2O_3	0·02
CaO	0·12
MgO	0·08
K_2O	none
Na_2O	none
Loss on ignition	0·21
Total .	99·97 per cent.

§ A similar quartzite, but less pure, has been worked at **Porth Wen,** near **Amlwch, Anglesey.**

The vein-quartz from **Slieve More, Achill Island** was formerly crushed and supplied by the Irish Industrial Minerals Company, **Westport.**

The chemical composition of a sample of the crushed rock supplied (quality No. 3) is as follows:—

SiO_2	99·20 per cent.
Al_2O_3	0·24
Fe_2O_3	0·04
CaO	0·09
MgO	trace
Loss on ignition	0·23
Total . . .	99·80 per cent.

The uncrushed rock contains 99·51 per cent. SiO_2 and 0·004 per cent. Fe_2O_3. Some of the iron seems to have been introduced as a result of crushing the material (see page 128).

The flaky form of the crushed product is seen in Plate IV. fig. 5

Mechanical analyses of numbered samples supplied are as follows:—

Quality	CS >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade: >0·1 mm.
0 ..	.		0·3 %	0·7 %	99·0 %	0·3 %
1 .. .		few grs.	3·5	1·8	94·7	3·5
1 *a*	...	2·0 %	17·9	36·5	43·6	19·9
2	0·2 %	9·0	53·5	23·5	13·8	62·7
3	1·0	85·5	11·6	0·4	1·5	98·1
4	54·9	42·9	0·5	0·2	1·5	98·3

Examination of the samples for heavy detrital minerals by means of bromoform reveals the fact that, in the crushed material of quality 3 as supplied, a large part of the crop of density greater than 2·8 (0·1 per cent.) consisted of rust-reddened metallic iron easily attracted by a bar-magnet. Most of the remainder of the residue consists of flakes of a greenish biaxial mica (0·3 mm. diameter), containing plates and dendritic growths of hematite.

Before the war, the No. 2 material fetched 27*s*. to 30*s*. per ton for use in the making of abrasive soaps.

§ A foliated micaceous quartzite has also been worked at **Kildownet** in the south of Achill Island.

At **White Rock**, about four miles north-west of **Tinahely, Co. Wicklow**, a knob of vein-quartz occurs associated with quartz-mica schists. The mass forms a prominent feature on the landscape, and is at least a hundred yards long by fifty yards wide. Quarrying indicates that it is more than thirty feet deep. The rock quarried is a pure white vein-quartz of good quality. It is carted to Tinahely Station by road and thence delivered on the quays at Arklow or Dublin. The cost at Arklow of the uncrushed rock is about 6*s*. 9*d*. per ton, and at Tinahely Station about 4*s*. 6*d*. Crushed, rolled, and screened material (1 inch to $\frac{1}{30}$ inch) can be delivered into an English port at from 28*s*. to 50*s*. per ton. Larger-sized material could be similarly delivered at about 25*s*. per ton.

The quartz is said to contain 99·50 per cent. of silica. The quarry is worked by Mr. E. Page, Woodenbridge, Co. Wicklow.

Similar vein-quartz has been supplied from near **Ynyslas** Station, **Cardiganshire**. The crushed product is far from well-graded, and its cost is prohibitive for glass-making.

Veins of quartz are of wide distribution among the older rocks of the west and north of Ireland, Wales, and Scotland. They are not often sufficiently thick or persistent to be of economic value. Samples have been collected from Anglesey, the Lleyn Peninsula, Bardsey Island, and other localities.

CHAPTER VIII.

BRITISH RESOURCES OF GLASS-SANDS, ETC. (*continued*).

B. DEPOSITS CARRYING ALUMINA AND SILICA.

Alumina commonly occurs in sands and rocks used for glass-making in the form of the mineral felspar or the decomposition product, kaolin (china-clay), which results largely from the alteration of felspar. Certain rocks—as, for example, those of the Triassic and Carboniferous Systems—are rich in decomposed felspars and contain a certain amount of clayey material. This renders their crushed products poorly-graded, but the small proportion of alumina present may actually be an advantage, as in the case of bottle-making, where strength and toughness are required in the glass. Unfortunately, most British sands bearing a high proportion of alumina contain also much iron, and are useless for the manufacture of glass-ware other than common bottles.

A prejudice against alumina in sands for bottle-making was formerly met with, but it is now slowly dying out. In rare cases alumina is even added to the batch for bottle-making. Dr. W. E. S. Turner, of the Department of Glass Technology in the University of Sheffield, is of the opinion that, far from having a tendency to cause devitrification, alumina if in moderate amount has just the opposite properties and will prevent glass from devitrifying. Experiments have shown that when alumina is added to a window-glass batch, the glass which is produced does not undergo devitrification when heated in a blow-pipe flame. If the amount of alumina is high, it is possible for a clouded glass to be produced, as when felspar itself is used. According to the investigations of Singer *, it is possible to add to a glass-batch containing alumina more sand and more lime, and to reduce in proportion the amount of alkali, thereby cheapening the cost of production.

Of the sands and rocks described or mentioned in the foregoing pages, those from Sandymount Strand (Dublin), Parsley Hay and Brassington (see below), Charlton, South Cave, Huttons Ambo, and Levenseat, carry appreciable, and sometimes large, quantities of alumina †.

The sand from Sandymount Strand is used in the Dublin black-bottle industry. To give greater "body" to the glass, broken lumps of Bridgwater or other homogeneous brick are added to the batch. The brick is red and is highly ferruginous, as the following analysis indicates :—

* F. Singer, 'Die Keramische Rundschau,' vol. v. 1915, "Ueber den Einfluss von Tonerde auf die Schmelzbarkeit von Gläsern."

† See note on page 34 referring to sand from Martinroda used for thermometer-glass.

Analysis of Bridgwater Brick.

SiO_2	58·20 per cent.
Al_2O_3	16·42
TiO_2	1·29
Fe_2O_3	6·74
FeO	0·13
CaO	7·37
MgO	3·02
K_2O	3·65
Na_2O	0·93
CO_2	0·13
P_2O_5	0·07
MnO	0·08
Loss on ignition [H_2O and carbonaceous matter.]	2·50
Total	100·53 per cent.

The addition of the brick increases the depth of colour of the bottles, and undoubtedly strengthens them by toughening the glass—a result of the addition of the 16½ per cent. of alumina. This is a distinct advantage where the bottles have shoulders and are required to stand considerable pressure from contained gases.

In the St. Helens district a baked clay is added to the batch for the same purpose. A partial analysis of such a baked clay from Messrs. Nuttall's works is as follows:—

SiO_2	63·99 per cent.
Al_2O_3	15·17
TiO_2	0·65
Fe_2O_3	6·13
Total	85·94 per cent.

"Spital sand" is used for bottle-making, and contains almost 3 per cent. of alumina. The sand from Worksop is similar in mineral composition and might well be more extensively used in the bottle industry of Yorkshire, which is located close at hand.

Eaglescliffe "sand," mentioned in Chapter X., is a chemically-treated rock of the same age. The iron-content has been very much reduced (see analyses), but the alumina, forming 3·51 per cent., has been retained. The Stiper Quartzite and the Appin Quartzite are felspathic, and in consequence contain about 2 per cent. each of alumina. The Port-a-cloy rock has already been described (page 93) and contains, before washing, 12·66 per cent. of alumina. A washed material from it contains still 0·23 per cent. of iron oxide (Fe_2O_3) and 11·57 per cent. of alumina. Kaolin-bearing sands and crushed rocks cannot be washed to reduce the iron-content without loss also of the alumina (see, for example, the analyses of Huttons Ambo sands on page 65: before washing, 3·68 per cent. Al_2O_3, 1·28 per cent. Fe_2O_3; after washing, 0·84 per cent. Al_2O_3, 0·03 per cent. Fe_2O_3).

In addition to the above, the following alumina-bearing sands and rocks may be mentioned :—

(a) Sands, Clays, etc.

§ **Kaolin,** as prepared in **Cornwall** and **Devon** from the altered and decomposed granite, is used in glass-making where resistant or tough glasses are required. It is added to the batch in the usual way, but since it is a refractory body, greater heat is required to get it into solution than is usually required in glass-making. Moreover, aggregates of the mineral sometimes form and are difficult to melt up. They tend to remain as "stones." Any natural sandy deposit therefore which is low in iron-content and rich in kaolin, and has its sand-grains coated evenly by the latter, is of considerable value for particular glasses such as those used for chemical and pharmaceutical purposes (laboratory apparatus, combustion tubing, thermometers, ampoules, etc.). Such materials cannot, of course, be well-graded.

The kaolin resources of England have been carefully described in detail by J. Allen Howe, in a Memoir of the Geological Survey, "A Handbook to the Collection of Kaolin, China-Clay and China-Stone in the Museum of Practical Geology" (1914). Since the production of the Handbook, fresh but smaller resources have been discovered at Holyhead Mountain, Anglesey (worked by W. Wild & Sons Ltd., Brassfounders, Liverpool St., Sheffield), and Port-a-cloy, Co. Mayo (The China-Clay & Felspar Company Ltd., Dublin), as well as a few other localities.

In the preparation of china-clay (of theoretical composition $Al_2O_3 . 2SiO_2 . 2H_2O$), great care is taken to eliminate all micas, etc., partly because of their coarseness and partly because of the alkalies and alkaline earths in their composition which render the clay less refractory. For glass-manufacture the small quantity of alkalies in the settlings known commercially as "micas" is not objectionable and may even be advantageous. An analysis of "coarse micas" mechanically separated at the Standardised China-Clay Company's Works at Roche, Cornwall, is as follows :—

SiO_2	48·18 per cent.
Al_2O_3	36·14
TiO_2	0·25
Fe_2O_3	0·98
CaO	0·13
MgO	0·28
K_2O	2·12
Na_2O	0·23
Loss on ignition	11·93
Total	100·14 per cent.

The tips of rejected coarse material from the kaolin workings in Devon and Cornwall contain high silica and fairly high alumina-content. The tourmaline could be extracted by electromagnetic

means, and the alumina is mostly present as micas, kaolin, and partially decomposed felspar. The deposits are poorly graded, containing much coarse quartz and felspar. It is a pity the material cannot be made use of; sands with a good proportion of alumina are desirable for certain glass-work, and a market is badly needed for the rejectamenta from the kaolin-works. The material is utilized for the making of refractory bricks.

§ Refractory Sands, etc., of Devonshire.

The deposits occur in two well-marked basins, south and north of Dartmoor respectively. The basin of Bovey has long been known and has frequently been described and discussed *. Kaolin-bearing sands and fireclays, associated with lignites, have been worked on a large scale at Heathfield, and also near Newton Abbot. For the greater part, the sands bear too much tourmaline (boro-silicate of aluminium and iron) to be of use for glass-making, and the electromagnetic separation of the mineral would prove too expensive. The deposits are of considerable value for refractory purposes.

The second basin occurs north of Hatherleigh and south of Torrington, in North Devon, and has not yet been described in detail. In recent years large open-cast workings and mines have been made in order to obtain the peaty clays and clayey sands for the making of fire-bricks and for pottery purposes. The material is kaolin-bearing and undoubtedly derived from the Dartmoor Granite. A chemical analysis of Torrington sand is given in the Table on page 157.

§ Sands, etc., from St. Agnes, Cornwall.

Sands of white to yellowish colour, felspathic and kaolin-bearing, occur in association with refractory clays near St. Agnes Beacon, Cornwall. The deposits, which occur on the 400 ft. platform, are believed to be of Pliocene age. They have been used as refractory materials, but are of limited extent and thickness. The principal pits are close to Beacon Cottage, one mile west-south-west of the Church and half a mile north of the Beacon (west and west-north-west of the Church). The best whitish sand occurs below red sand and "candle" clays. The material can be shipped from Trevanaunce Cove or Chapel Combe near by, or carted to St. Agnes Station (two miles). The resources of the area would very soon be exhausted.

§ Kaolin from Anglesey.

On Holyhead Mountain, Anglesey, several dykes occur in the pre-Cambrian quartzite (see page 96). They have a north-south strike and vary in width from about twenty feet to a very small

* See, for example, Mem. Geol. Surv., "The Geology of the Country around Newton Abbot" (Sheet 339), 1913.

amount. It is difficult to say what the original rock of these dykes has been. In places, the clay now filling them is somewhat sandy, but in others the clayey material is so pure as to discountenance the suggestion that they were originally microgranite. The presence of quartz-veins in the adjacent rock, and at times the abundance of limonitic matter in the dykes, together with plentiful evidence of alteration of the quartzite walls of the veins and dykes, suggests hydrothermal action and that the dyke-materials in their present form may be secondary in origin. The dykes at present being worked occur in Messrs. Wm. Wild & Sons' quarry, where the clay has been used as a binder for the broken quartzite in making "gannister" for lining steel-converters. A very good grade kaolin has been washed out of the material from another of these dykes. The chemical composition of a sample of the raw material, which is a clayey sand, is as follows:—

SiO_2	94·90 per cent.
Al_2O_3	2·31
TiO_2	0·45
FeO	0·48
Fe_2O_3	0·15
CaO	0·13
MgO	0·12
K_2O	0·74
Na_2O	0·02
MnO	trace
Loss on ignition	0·68
Total	99·98 per cent.

The alumina-content of this sample is surprisingly low. It probably cannot be taken as typical.

§ The Refractory Sands of Derbyshire and Staffordshire.

The irregular accumulations of sands and clays which occur in hollows in the surface of the Carboniferous Limestone district of Derbyshire and Staffordshire are well-known on account of their highly refractory character. They have been mentioned by Geo. Maw, J. Allen Howe, Dr. A. Strahan, and others, but no systematic account of them seems to have been written. At present they are utilized for the making of high-class silica-bricks, when variability in iron-content, up to several per cent., is not detrimental. Selected deposits of white to cream-coloured sand or clayey sand might be of considerable value for glass-making, but the available resources are very limited and it will be difficult to keep to sample.

These kaolin-bearing sands are free from alkalies, lime, etc., and at times carry very little iron oxide. They are worked at Carsington Pastures, near Harborough Rocks, at Longcliffe, Low Moor, Friden, Blake Moor, Parsley Hay and Alsop en le Dale in Derbyshire, and also at Ribden in Staffordshire. The hollows are clean-sided, with fresh limestone walls, steep and sometimes

overhanging. The limestone displays no evidence of ordinary weathering. Signs of stratification are visible in the material filling the hollows; the association is not turbulent as described, but appears to yield evidence of a definite order related to the succession of the Triassic sediments, which at one time were continuous over the whole district. Bunter Sandstone, the Pebble-bed Keuper Marls, and black shale probably belonging to the Rhætic have foundered into the hollows. The oldest deposits occur nearest the walls of the basin. The various sediments have suffered a curious alteration, characterized by the production of kaolin material and the almost complete elimination of alkalies and alkaline earths. The appearance of the workings, especially of the white deposits of the central and deeper portions of the basins, is strikingly similar to that of the china-clay pits of Devon and Cornwall. One area at least reproduced the conditions of the Bovey deposits—indeed Geo. Maw noted the similarity long ago,—lignites, pipe-clays, and refractory sands indicating the filling up of a swampy hollow with vegetation and kaolin-mud at a time when the bulk of the Triassic rocks had been removed, but when foundering was still in progress.

Chemical analyses of some of the purest of these deposits are :—

	Parsley Hay.	Brassington.	Newhaven.
SiO_2	74·54	90·40	98·17 per cent.
Al_2O_3	18·04	6·56	0·71
TiO_2	n. d.	n. d.	0·42
Fe_2O_3	0·05	0·18	0·025
CaO	0·19	0·16	0·11
MgO	none	trace	0·07
K_2O	n. d.	n. d.	0·09
Na_2O	n. d.	n. d.	0·02
Loss on ignition	7·24	2·48	0·41
Totals	100·06	99·78	100·025 per cent.

The composition of the Parsley Hay material corresponds to a mixture of about 53 per cent. of pure silica sand, and 45 per cent. pure kaolin (of composition $Al_2O_3 . 2SiO_2 . 2H_2O$).

Mechanical analyses of some of the deposits, which are necessarily not well-graded, since they are clayey sands, are :—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	S. >0·01 & <0·1.		C. <0·01 mm.	S. Total sand-grade >0·1 mm.
rsley Hay	0·3 %	20·2 %	35·7 %	13·5 %		30·3 %	56·2 %
assington	1·5	71·4	11·8	2·1		13·2	84·7
				cs. >0·05.	fs. <0·05.		
oden	4·6	43·6	23·8	0·6	10·5	16·9	72·0
whaven	0·2	49·9	30·4	1·0	10·9	7·6	80·5
ngcliffe	2·2	58·6	23·7	0·7	5·2	9·6	84·5
rsington	2·0	63·7	11·0	0·8	4·1	18·4	76·7

The mineral assemblages of certain of the deposits include well-rounded grains of heavy minerals. Among the species noted were anatase, apatite, cassiterite, epidote, rutile, spinel, staurolite, and zircon.

§ Deposits in North Wales.

Similar materials, but more siliceous and apparently derived also from Millstone Grit or Carboniferous sandstones which have long since been worn away, occur in the surface of the Carboniferous Limestone areas of Flintshire (**Halkyn, Rhes y cae, Pant du,** etc.), Denbighshire (near **Llandudno** and **Abergele**), and Carnarvonshire (**Conway**, etc.). Analyses of some of these deposits are given in the Tables on pages 157 and 164. With the possible exception of Abergele, they are of small extent and for the most part not now worked.

In the recent quarrying of the limestone at Kinmel Park Camp, near **Abergele**, a fair amount of this material seems to have been exposed. The quarry, however, has since been partly filled in, and little can be seen except clayey matter which is reminiscent of the Derbyshire deposits and may be derived from the Trias. Indications are seen all over the area of similar deposits and of likely hollows, and explorations might reveal supplies of valuable refractory materials. The white sand from Abergele (Kinmel Park) forwarded to the writer by Mr. R. D. Griffith of Bethesda, is rather sugary in character, containing many compound grains. It may have been derived from the Millstone Grit, and is much less aluminous than most of the other deposits mentioned. Its chemical composition is :—

SiO_2	99·35 per cent.
Al_2O_3	0·54
Fe_2O_3	0·04
Loss on ignition	0·36
Total	100·29 per cent.

Alkalies and alkaline earths not determined; probably absent.

It is of a good white colour and does not change on ignition. The mechanical analysis indicates that treatment by washing and screening would improve it :—

>1 mm., 2·6 %; $>0·5$ & <1 mm., 8·8 %; $>0·25$ & $<0·5$, 77·7 %; $>0·1$ & $<0·25$, 8·6 %; $>0·01$ & $<0·1$, 2·3 %; $<0·01$, none. Total sand-grade, $>0·1$ mm., 97·7 %.

$$\left[\frac{VCS}{2·6}, \frac{CS}{8·6}, \frac{MS}{77·7}, \frac{FS}{8·8}, \frac{s}{2·3}, \frac{c}{0·0}; \frac{S}{97·7}.\right]$$

The detrital mineral residue is very small in amount (0·01 per cent.) and shows the presence of minute zircons and rutiles

(0·02 to 0·05 mm. in diameter), ilmenite and limonite, anatase, and muscovite flakes (0·4 mm. diameter).

Without further exploratory work, no opinion can be given as to the available resources. In any case, the material has no great areal extent; it merely occupies hollows and cracks in the Carboniferous Limestone.

CHAPTER IX.

British Resources of Rocks used in Glass-making (Felspars, etc.).

Siliceous Rocks bearing Alumina and Potash.

Although large quantities of rocks rich in alumina and silica occur in the British Isles, few contain little or no ferruginous material. The otherwise pure felsites and rhyolites are open to this objection. The chief rocks, therefore, which may be of value to the glass-manufacturer are pegmatites, aplites, microgranites, and modified granites free from iron-bearing minerals. Some likely-looking rocks were analysed and yielded the following results:—

	(1)		(2)	(3)
SiO_2	80·12		82·88	78·84 per cent.
Al_2O_3	10·68		9·39	10·50
TiO_2	0·09		0·15	0·14
FeO	0·49		0·56	0·26
Fe_2O_3	0·06		0·22	0·33
CaO	1·01		0·09	0·20
MgO	0·63		0·20	0·07
K_2O	1·42		1·88	8·65
Na_2O	3·44		3·98	0·41
BaO	0·01		trace	0·03
MnO	0·05		0·01	0·02
H_2O+	0·80		0·48	0·57
H_2O-	0·28		0·13	0·10
CO_2	1·20	Cl	trace	trace
P_2O_5	trace		none	none
ZrO_2	0·03		0·02	n. d.
S	0·09		none	0·23
	100·40		99·99	100·35 per cent.
Less O for S	0·03			·08
Total	100·37			100·27 per cent.

(1) Granophyre from Brandy Gill (Carrock Fell Syndicate Co.).
(2) Felsite from Wicklow, H. 5.
(3) „ „ Tramore (Waterford), C 2.

Other partial analyses are given in Table III. page 158. These analyses are given as fairly typical examples of what may be expected, so far as glass-making is concerned, in rocks of this character. The iron-content is too high for good glass-making.

The best and most accessible British rocks of this kind (pegmatites, aplites, etc.) are mentioned below. They generally occur as dykes, that is, more or less narrow parallel-sided sheets of rock intruded into other rocks, usually standing almost vertically. The outcrop of such rocks at the surface is rarely more than

a hundred yards wide, and is often only a few feet, but it may be of considerable length, and the rock may extend to a great depth.

The pegmatites consist mainly of quartz and felspar crystallized together. The felspar may contain potash, soda, and lime. Those rocks which bear potash are most in demand by the potter and glass-manufacturer, and have therefore been investigated more fully.

Felspar is chiefly used in the glass-industry of this country in the manufacture of chemical ware, being imported for the purpose from Norway and Sweden. Owing to the fact that felspar is usually delivered in the form of either pegmatite or graphic granite, the exact composition of the rock is always liable to vary in successive consignments. The use of kaolin (china-clay) is open to the same objection, but to a smaller degree. For the best qualities including optical glass, where, however, the requirements of raw materials other than sand are relatively small in amount, it is found advisable to add the soda, potash, lime and alumina, in a form of purity and in the required proportions. For second-grade glass-ware, the use of felspar is a convenient and cheap means of adding both potash and alumina. Care must be taken, of course, to ensure that the iron-content of the felspar-rock is low (as it is in many British pegmatites). Little use is made of felspar at the present time in the bottle-trade. As already mentioned, the requisite alumina-content is obtained in rough work by the addition to the batch of brick, baked clay, or even raw ball-clay. For flint-glass bottles, pale bottles, etc., where strengthening and toughening are required, china-clay is sometimes used. British felspars, if properly worked, should be cheaper to procure than foreign material, and might be used with advantage much more extensively.

Potash Felspars.

The chief potash-bearing felspars which occur in Great Britain (but not in Ireland) have already been dealt with in one of the Special Resources Memoirs of H.M. Geological Survey *, recently issued. One at least of those described, besides others not mentioned, are at present being worked.

The following account includes notes on Roche felspar additional to those published.

Felspar from the old quarry of Tresayes, near Roche, Cornwall.

The following description of the deposit is given in the Memoir of the Geological Survey upon Bodmin and St. Austell, 1909 (pages 61, 62):—

"At Tresayes Downs there is a wide extremely coarse pegmatite vein in the Killas, a few yards from the margin of the granite. It

* "Special Reports on the Mineral Resources of Great Britain. Vol. v. Potash Felspar, etc." Mem. Geol. Survey, 1916.

consists mainly of enormous orthoclase crystals, roughly parallel and arranged vertically, some of which are graphically intergrown with quartz. Some quartz occurs interstitially, frequently associated with tourmaline and a little fluorspar. There is also a little pale mica. The vein has a north and south direction nearly parallel with the margin of the granite at this place, and is nearly 50 yards in width. The vein was formerly worked for felspar for use in glass-making, but the work was abandoned about 1880."

Some half-a-dozen trial holes have recently been put down and the rock proved over an area one hundred yards long by fifty yards wide. At the time of the writer's visit, the pegmatite was visible in the old quarry to a depth of about ten feet, the bottom being occupied by water. The pegmatite is rather iron-stained along joint-planes and contains crystals of tourmaline. For glass and pottery purposes, the felspar is hand-picked. The best means of transport is down the small valley to Carbis siding. A mineral line already extends almost up to the quarry, which at the time of writing has once more been opened up. Good-quality felspar is being extracted.

The following are analyses of Roche felspar:—

	(1)	(2)	(3)	(4)
SiO_2	65·00	65·33	62·98	64·21 per cent.
Al_2O_3	19·00	19·16	18·92	19·66
Fe_2O_3	0·50	0·50	1·18	0·18
CaO	1·57	1·68	0·75	0·35
MgO	tr.	tr.	0·36	0·07
K_2O	10·37	10·37	11·68	12·35
Na_2O	2·40	2·40	4·18	2·79
H_2O	0·83	0·50	0·30	0·73
Totals ..	99·67	99·94	100·35	100·34 per cent.

(1) & (2) J. A. Phillips, Phil. Mag. Feb. 1871.
(3) W. Crossley, 281 Dunstan's Hill, E.C.
(4) Dr. H. F. Harwood. Analysed with especial regard to glass-making requirements. No titanium or barium was present.

The quantity of iron in (3) may be due to included tourmaline crystals.

The chemical analysis (4) corresponds to the following approximate mineral composition (percentage weights by calculation):—

Potash-felspar	73·18 per cent.
Albite (soda-felspar)	23·67
	96·85
Remainder (mainly quartz) .	3·49
Total	100·34 per cent.

Other dykes of pegmatite are now being opened up at **Kernick,** near **Trevisco,** and on **Trelavour Downs.** Chemical and mineral analyses of these deposits will be found in Table IV., page 160.

Felspar from Pegmatites occurring in Scotland.

A fairly full account of the most accessible pegmatite veins in Scotland has been given in the memoir cited*. The veins at three localities (1) between Lochs Laxford and Inchard, (2) between Durness and Eriboll, and (3) at Overscaig, Loch Shin, are described in detail with accompanying sketch-maps for the first and second localities. The veins at the first two places occur in the Lewisian Gneiss in the extreme north-west of Scotland, where the working conditions and questions of transport leave much to be desired. The Overscaig pegmatite occurs in the Moine Schists and is also difficult to work from rail or boat. The estimated resources from the most accessible veins at the first locality mentioned are not less than 190,000 tons. At the second locality, not less than twelve million tons of pegmatite are available.

A chemical analysis of the rock from the third locality is given as follows:—

SiO_2	72·94 per cent.
Al_2O_3	14·26
TiO_2	0·06
Fe_2O_3	0·21
FeO	0·22
(CoNi)O	nt. fd.
CaO	0·23
MgO	0·08
K_2O	7·42
Na_2O	3·49
Li_2O	trace
BaO	0·25
H_2O at 105° C.	0·05
H_2O above 105° C.	0·17
P_2O_5	0·49
MnO	0·11
FeS_2	nt. fd.
CO_2	0·06
Total	100·04 per cent.

E. G. Radley (Anal.)

Calculation from this analysis gives (percentages by weight):—

Microcline	43·96
Albite	29·61
Felspar	73·57
Minor Constituents	2·38
Quartz ..	24·09 by difference.
Total	.. 100·04 per cent.

Chemical analyses carried out by Dr. Harwood, with especia reference to the requirements of the glass-industry, of samples c

* "Special Reports on the Mineral Resources of Great Britain. Vol. Potash Felspar, etc." Mem. Geol. Survey, 1916.

Scottish pegmatites collected by the writer may be added for comparison:—

	(1)	(2)	(3)
SiO_2	69·05	71·53	70·36 per cent.
Al_2O_3	16·84	15·33	15·97
TiO_2	none	trace	none
Fe_2O_3	0·07	0·05	0·08
CaO	0·21	0·28	0·12
MgO	0·06	0·15	0·08
K_2O	10·08	10·43	10·42
Na_2O	2·83	1·91	2·19
BaO	0·12	0·60	0·53
Loss on ignition	0·42	0·21	0·29
Totals	99·68	100·49	100·04 per cent.

(1) From the exposure on the shore of Loch Shin, a little more than 600 yards south-east from Overscaig Farm.

(2) From a vein 300 yards north of Badcall Pier, about a mile north-west from Laxford Bridge, Sutherlandshire.

(3) From a thick belt of veins on the north-west slope of Beinn Ceannabeinne, near Durness, close to locality A of the sketch-map in the Report on Potash-Felspar by H.M. Geological Survey.

The approximate mineral composition of each sample calculated from these analyses is:—

	(1)	(2)	(3)
Potash felspar	59·71	61·80	61·74 per cent.
Albite (soda-felspar)	24·01	16·20	18·58
	83·72	78·00	80·32
Quartz and other constituents	15·96*	22·49*	19·72* by difference.
Totals	99·68	100·49	100·04 per cent.

The following note † as to the composition of the Scottish pegmatite veins is of importance to glass-manufacturers:—

"The pegmatite material consists predominantly of quartz and felspar. Iron-bearing minerals, such as biotite and hornblende, are present, but generally constitute less than 1 or 2 per cent., and though the proportion may sometimes reach 5 per cent., it is only in certain infrequent bands. Where the pegmatites are uncrushed, these ferromagnesian minerals (which tend to be associated with the plagioclase felspars) could be hand-picked from the quarried material."

Such iron-bearing minerals as biotite and hornblende are very undesirable in felspars used for glass-making. The iron-percentage in the analysis quoted above ($FeO+Fe_2O_3$, 0·43 per cent.) is too high for good glass-making.

* The content of barium felspar (celsian) in 1, 2, and 3 is 0·48 %, 2·42 %, and 2·14 % respectively. The remaining minor constituents are small in amount.

† "Special Reports on the Mineral Resources of Great Britain. Vol. v. Potash Felspar, etc." Mem. Geol. Survey, 1916, p. 9.

The average mineral composition of the pegmatites is said to be:—quartz 24·8, and felspar 75·2 per cent. Figures in particular analyses vary between the extremes:—quartz 17·65, and felspar 82·35 per cent.; quartz 39·0, and felspar 61·0 per cent.

The average value for the potash-percentage in the Sutherland felspar is stated by H.M. Geological Survey to be 12·81, which agrees closely with that of felspar from other localities. The potash-content of the pegmatites would thus amount to about 9·2 per cent., which is in accord with the results of the analyses made by the Survey.

For the following notes, published by permission of the Director of the Geological Survey of Ireland, on the Belleek felspar, the writer is indebted to Mr. W. B. Wright, B.A., F.G.S:—

The Pegmatite Deposits of Belleek, Co. Fermanagh.

"The felspar deposits of Belleek, the presence of which in the district was one of the inducements which led to the establishment of the Belleek Pottery, occur in the area of gneissose rocks to the north of Belleek and Castlecaldwell. They are not, however, exploited at the present time, because the requirements of the Pottery are so small that it would not pay anyone to mine for the purpose of supplying this demand alone, as long as materials can be obtained from Norway at prices which are reasonable. The Manager of the pottery states that from his point of view there is little to choose between the native felspar and that which is now imported.

"The felspar occurs as the main constituent of pegmatite dykes, which are found traversing the gneissose rocks. It is, to a varying extent, graphically intergrown with quartz, and in some places penetrated by coarser veins of quartz. White mica also occurs here and there as an impurity.

"The following are the localities (as far as they could be ascertained by local enquiry extending over two days) in which attempts have been made in the past to test the extent and quality of the felspar-bearing veins.

"(1) Townland of Derryrona Glebe, north of Lough Scolban, and three and a half miles E.N.E. of Belleek. The pit is now filled up, but the vein is reported by a local farmer to have been four feet wide. There is a heap of felspar containing about three tons beside the pit. It is graphically intergrown with quartz in the proportion of say one part of quartz to three or four parts of felspar. The felspar crystals are sometimes as much as 18 inches square.

"(2) Townland of Scardans Lower, two miles north of Castlecaldwell. The vein appears to be about 4 feet wide and the shaft that has been sunk in it is reported to be about 30 feet deep. The felspar got out here is not so pink as elsewhere. The crystals are up to a foot in length. There is, if anything, less graphically

intergrown quartz than at Lough Scolban. The vein is said to have a definite wall and to part easily from it.

"In this townland there are several other localities where felspar can be seen exposed at the surface, or where the local farmers state that explorations have been carried out in the past.

"(3) Townland of Larkhill, in the bog to the north of Croagh More. a vein has been opened up in this locality running N. 35 E., and dipping N.W. at 50 or 60 degrees. It appears to be 4 or 5 feet thick and was excavated to a depth of about 20 feet at the N.E. end. There is a heap of about 20 tons at one side. It varies greatly in quality and in its quartz content, which seems to be somewhat greater than at localities (1) and (2).

"There have been some other minor openings in the same townland

"(4) On the moorland between Loughs Unshin and Columbkille, about a quarter of a mile S.W. of Lough Unshin and two and a half miles north of Belleek there is a nine-foot vein of pegmatite running W. 35 N. and traceable for about 50 yards. Only surface quarrying has been done on this vein. It varies a good deal in quality. In some places it contains a fair amount of quartz and mica, but in others it is almost entirely composed of large felspar crystals with minute graphic intergrowth of quartz.

"The localities numbered (1) to (4) are, as regards size and content of the veins, the best which are at present known in the district. Veins up to two feet in thickness occur in many places, as for example at Garvary, near Castlecaldwell, where several openings have been made. These, however, are hardly worth considering until it is known that the larger veins could be made to pay.

"As regards the continuity, laterally and in depth, of these veins or dykes of pegmatite, it is impossible to make any confident statement, as the country in which they occur is so much obscured by drift and bog. Smaller veins in better exposed ground are seen to be fairly continuous for considerable distances but vary much in width. There ought to be about the same ease or difficulty in following them as there is in following an ordinary lode, and they have about the same chance of maintaining their width.

"From the nature of the rocks and the reports regarding the shafts already sunk, it is not anticipated that any difficulty would arise from water in the mines. A certain amount of felspar could undoubtedly be got out by surface quarrying, but in the end mining would have to be resorted to.

"The following are distances from the railway :—

"Locality (1). 1 mile from Castlecaldwell Station.
(2) & (3). 1 mile from rail, 2 miles from Castlecaldwell Station.
(4). 2 miles from Belleek Station.

"The railway freight for coal from Londonderry to Belleek is

4*s.* 6*d.* a ton. The harbour at Ballyshannon is difficult of navigation."

Chemical analyses of the Belleek Pegmatite (by Dr. H. F. Harwood and Mr. A. A. Eldridge) are as follows :—

Locality	(1)	(2)	(3)	(4)
SiO_2 ..	73·18	73·07	65·74	70·96 per cent
Al_2O_3 .	14·58	14·71	18·36	15·53
TiO_2	none	none	none	none
Fe_2O_3	0·06	0·05	0·06	0·27
CaO	0·22	0·22	0·21	0·28
MgO	0·08	0·05	0·13	0·07
K_2O	10·48	10·14	13·08	10·95
Na_2O	1·52	1·60	2·07	1·55
BaO	trace	0·02	0·03	0·16
Loss on ignition ..	0·27	0·46	0·25	0·48
Totals . .	100·39	100·32	99·93	100·25 per cent.

The approximate mineral composition of each sample calculate from these analyses is :—

	(1)	(2)	(3)	(4)
Potash felspar .	62·10	60·07	77·49	64·90 per cen
Albite (soda-felspar)	12·89	13·57	17·56	13·15
	74·99	73·64	95·05	78·05
Quartz and minor constituents	25·40	26·68	4·88	22·20
Totals	100·39	100·32	99·93	100·25 per cen

A few other workable veins of pegmatite were also visited i this area by the writer. A chemical analysis of rock from Garvar Wood is given in Table IV. page 160. At a very conservativ estimate many thousands of tons occur. On the whole, these Iris deposits are more easy of access than the Scottish and seem to hav less quartz intergrown with the felspar ; their soda-content is als less. Occasionally stringers of ferromagnesian minerals are me with, as in the Scottish pegmatites, but hand-picking will generall remove these.

At **Ballymanus**, near **Aughrim** (Co. Wicklow), felspar was sai locally to have been worked and used in glass-making or potter work. Prof. Grenville A. J. Cole, F.R.S., Director of the Geologica Survey of Ireland, has kindly examined G. H. Kinahan's field-map for the writer, and finds upon them dykes (running from north-east to south-west) of quartz-felspar rock at Ballymanus. Working, except for the granite, has been given up for a long time.

In point of bulk the Scottish deposits stand first, but their relative inaccessibility reduces the value of the large resources present. The Cornish pegmatites are very limited in quantity, and are liable to contain tourmaline. The chief iron-bearing mineral in the pre-Cambrian pegmatites is biotite. Other occurrences of

felspars in Argyllshire, Co. Donegal (Fintown, Dooey, Glenties and Gweebarra), and Co. Mayo (Belmullet, Erris Head, Doolough, etc.) have been visited and their workability is being considered. They will shortly be described in detail*; in the meantime, chemical and mineral analyses are given in Table IV. page 160.

For comparison with the analyses of English, Scotch, and Irish felspars, may be quoted that of one of the Swedish felspars imported in large quantities for glass-making and pottery purposes†.

SiO_2	65·73 per cent.
Al_2O_3	19·01
TiO_2	none
Fe_2O_3	0·23
CaO	0·27
MgO	0·28
K_2O	14·01
Na_2O	2·21
Loss on ignition	0·36
Total	99·10 per cent.

The Scandinavian felspar at present in use at the Belleek Pottery has the following composition (H. F. H. & A. A. E.):—

SiO_2	65·60 per cent.
Al_2O_3	19·05
TiO_2	none
Fe_2O_3	0·02
CaO	0·26
MgO	trace
K_2O	12·12
Na_2O	3·08
Loss on ignition	0·28
Total	100·41 per cent.

Analyses of "Mixed Stone" and "Purple Stone" are also given:—

	Mixed Stone.		*Purple Stone.*
SiO_2	72·15		70·31 per cent.
Al_2O_3	16·28		16·62
TiO_2	0·20		0·17
Fe_2O_3	1·45	FeO	1·50
MgO	0·20		0·08
CaO	1·65		1·50
K_2O	5·01		5·69
Na_2O	1·50		2·62
Loss on ignition	1·15		1·25
Totals	99·59		99·74 per cent.

* 'An account is being published by the writer in the Trans. Soc. of Glass Technology,' vol. ii. (1918). Dr. A. Campbell has recently dealt with further Scottish resources in a paper before the Edinburgh Geological Society (Jan. 1918). Additional supplies have since been discovered and will shortly be described.

† Trans. Ceramic Soc. vol. xii. (1912–13) p. 65.

With these may be compared the analyses made by Dr. H. F. Harwood of china-stone from the West of England China Stone & Clay Company Ltd., St. Austell:—

SiO_2	75·23 per cent.
Al_2O_3	14·27
Fe_2O_3	0·08
CaO	1·64
MgO	0·20
K_2O	4·35
Na_2O	2·81
Loss on ignition	1·44
Total	100·02 per cent.

Duplicate determination of SiO_2, 75·19 per cent.

This rock is crushed and ground to a fine powder in the works at Par, and is sent to the Potteries. The analyses are quoted as indicating that china-stone and related material, if they can be secured free from, or with a low percentage of, iron oxide, may be of considerable value to the glass-trade as sources of alumina and silica, and at times also of potash.

The British resources of china-stone have been fully dealt with in the Memoir quoted above ("A Handbook to the Collection of Kaolin, China-clay, and China-stone in the Museum of Practical Geology," Mem. Geol. Survey, 1914).

The following rock is of a similar character:—

Meldon Rock and "Sand." ("Devonshire Hard Purple Stone.")

Worked by the Meldon Valleys Co., c/o Messrs. Fox, Roy, & Company Ltd., Plymouth.

Maps.—Geological: Old Series, 1-inch, Sheet 25.
6-inch, Devon, Sheet 76 S.E.

Situation.—*Lat.* 50° 43′ 0″, *Long.* 4° 1′ 50″ W.

The quarries occur about half a mile east-north-east of Meldon Church and near the viaduct of the L. & S.W. Railway, about four miles south-west of Okehampton.

Formation.—Aplite dyke intrusive into Culm Shales (Carboniferous).

Description.—The rock occurs as a broad dyke running roughly parallel with the edge of the Dartmoor Granite, and separated from it by an outcrop of Carboniferous (Culm) Shales about sixty feet or more broad. The rock is a fine-grained aplite, varying in colour from grey to pale purple. One band runs very true to sample, and the good conditions of quarrying, the water-power present, and proximity of the L. & S.W. Railway, permit profitable working and crushing. Water-power and therefore electric-power being available, it is possible that at some later date, if the market permits it, washing, screening, and also electromagnetic treatment will be instituted to grade the product and free it from some of its iron.

chemical analysis of the rock is as follows:—

SiO_2	71·07 per cent.
Al_2O_3	16·79
TiO_2	0·06
Fe_2O_3	0·27
CaO	0·87
MgO	0·05
K_2O	3·83
Na_2O	4·92
Cl	trace
Loss on ignition	1·87
Total	99·73 per cent.

Duplicate determination of SiO_2 gave 70·98 per cent., and of K_2O, 3·81 per cent.

The iron-content of a sample of the crushed but untreated product is 0·15 per cent. FeO (Fe_2O_3 absent).

The mechanical analysis of the crushed product is as follows, but it should be mentioned that no attempt has yet been made commercially to grade the "sand."

>2 mm., 24·6 % ; >1 mm. & <2 mm., 18·5 % , >0·5 & <1 mm., 10·1 % ; >0·25 & <0·5, 20·2 % ; >0·1 & <0·25, 12·5 % , >0·01 & <0·1, 8·2 % ; <0·01, 5·9 %. Total sand-grade, >0·1 mm., 85·9 %.

$$\left[\frac{G}{24\cdot6},\ \frac{VCS}{18\cdot5},\ \frac{CS}{10\cdot1},\ \frac{MS}{20\cdot2},\ \frac{FS}{12\cdot5},\ \frac{S}{8\cdot2},\ \frac{C}{5\cdot9};\ \frac{G\ \&\ S}{85\cdot9}.\right]$$

The mineral assemblage in the rock is a full and interesting one. Apart from the minerals occasionally occurring in veins, etc. (axinite, green tourmaline, lithionite, fluor-spar, etc.), separation with bromoform enabled the following to be identified:—greenish and pale yellowish tourmaline, purple to colourless fluor, topaz, ilmenite, zircon in very small grains, muscovite, etc.

The crushing strength is 24,100 lbs. per square inch.

The rock may be valuable for the alumina it contains and also for the proportion of potash. For bottle-glass, the addition of limestone and alkali only is required. The rock is at present worked for pottery purposes, the crushed material being supplied at 15*s*. per ton. The freight to Staffordshire is now about 19*s*. per ton; before the war it was about 11*s*. The available resources are very considerable.

Potash-bearing Sands.

Very few of the minerals which occur in sands or rocks carry potash. The felspars have already been mentioned. Muscovite, or potash-mica, rarely occurs in quantity in Britain. As a partial decomposition product of felspar (of which the final stage is represented by the formation of kaolin), it occurs in the "micas" of the china-clay works (see page 100 for analysis, etc.). The amount of ferruginous impurity in these "micas" almost prohibits their use for glass-making. The only other potash-bearing mineral of

anything like common occurrence is glauconite, which is a silicate of iron, aluminium, and potassium. It has been used as a fertilizer because of its potash-content, and it is also of service for softening water. The mineral varies in colour from olive and deep bluish-green to such pale tints as to be practically colourless. It does not appear to have a fixed chemical constitution—indeed, the term probably includes a number of minerals of similar composition, but with varying quantities of iron, potash, soda, etc. Being an iron-bearing material, it cannot be utilized directly in glass-manufacture. Chemical analyses of some samples of glauconite are as follows:—

	(1)	(2)	(3)
SiO_2	49·42	50·42	46·91 per cent.
Al_2O_3	10·23	4·79	7·04
Fe_2O_3	16·01	19·90	23·06
FeO	3·00	5·96	2·64
MgO	3·78	2·28	4·40
CaO	0·31	3·21	2·95
K_2O	7·91	7·87	7·31
Na_2O	0·26	0·21	0·91
H_2O	8·08	5·28	4·71
P_2O_5	.	tr.	.
Totals . .	99·00	99·92	99·93 per cent.

(1) Rome.
(2) A Continental Glauconite.
(3) Channel Islands.

Some highly glauconitic deep green British sands have the following composition:—

	(1)		(2)
SiO_2	60·61		44·76 per cent.
Al_2O_3	9·73		5·62
TiO_2	0·70		0·45
Fe_2O_3	9·67		9·21
FeO	0·45		2·05
CaO .. .	1·22		4·56
MgO	1·89		2·20
K_2O	2·98		4·40
Na_2O	0·33		0·09
P_2O_5	0·13		0·02
		H_2O+	3·24
		H_2O-	2·48
		CO_2	10·64
		MnO	0·07
		Cl	trace
		BaO	trace
Loss on ignition . ..	12·38		
Totals	100·09		99·79 per cent.

(1) From the Thanet Beds at Bramford, near Ipswich.
(2) From the Upper Greensand, Collin Glen, Belfast.

The potash-content of other British glauconites will be found in the Table on page 159.

It may be possible in the future to utilize glauconite as a source of potash, but no British deposits yet found carry sufficient of that compound. A satisfactory chemical process must first be devised and made commercial. Although the potash-percentage is lower than in potash-felspar, the supplies of glauconite are large and widely distributed.

Numerous processes have been worked out for extracting the potash from felspar. A summary of some of these is given in the "Special Reports on the Mineral Resources of Great Britain. Vol. v. Potash-Felspar, etc."—an account similar to that in the Mineral Resources Reports of the United States Geological Survey. Reference may also be made to "The World's Supply of Potash," Bull. Imperial Institute, 1915. A modification of earlier processes has been suggested by E. A. Ashcroft (Inst. Mining & Metall. Dec 1917). One of the most promising and interesting of recent processes is that suggested by Frazer, Holland, and Miller (Journ. Indust. & Engin. Chemistry, vol. ix. No. 10, page 935, Oct. 1917); it aims at producing aluminium sulphate, with potash as a by-product.

The results on British felspars of procedure patented by Mr. J. Rhodin were given in the 'Journal of the Board of Agriculture' for February 1917 (Br Pat. 13,118 of 1914, 21,697 of 1911, and 16,780 of 1899).

CHAPTER X.

Special Treatment of Sands and Rocks.

Sands, like many other natural products, can be improved by washing. If the process is carried out effectively, a third-quality sand may be brought up to the rank of second-quality, but it does not produce, in the case of most British samples, a first-quality glass-sand. Moreover, the question of extra expense due to washing (and sometimes drying also) and consequent additional handling and movement, is here an important factor, since very large quantities of second- and third-rate sands are used for making glass for lamp-chimneys, electric-light globes, flint-glass bottles, window-glass, commoner table-ware, etc., individual firms each using as much as three hundred tons of sand a week.

Colour of Glass-Sands—Although in the field a considerable number of sands appear by comparison to be white, it is remarkable how very few are snow-white. The colour is frequently a good indication of the relative freedom of the sand from oxide of iron. The best English sands are locally white, but usually grey, cream-coloured, or faintly yellow or brown. To realize the true colour, samples may be placed upon white paper or compared with Fontainebleau sand. Small quantities may also be mounted in clove oil and examined under the microscope, when the faint yellow, brown, or grey pellicles of ferruginous material are easily visible.

A dark colour is not necessarily an indication of much iron; organic matter, which may subsequently be burnt out, produces this effect. A pink colour may be due to pink quartz and not to iron oxide. Similarly, glass itself may be water-white and brilliant, and yet contain no small percentage of iron.

(a) *Washing.*—Hematite-coated grains (like those in Permian and Triassic deposits) cannot be cleaned without very great difficulty, even where the coating is thin and the sand pale-coloured. In the case of sand-grains having a thin pellicle of limonite, mere washing by water may improve the quality considerably. Second-class sands from the Lower Greensand of Aylesbury, Leighton Buzzard, and King's Lynn have been improved and made suitable for flint-glass work in this way, but the results are not even then so good as the best of the Aylesbury or Lynn sands actually found in the quarries. The best sands are not improved in the matter of iron-percentage by washing, but the adoption of washing does obviate to a considerable extent the trouble of careful selection, and enables variable sands to be profitably exploited.

apart from the question of the increased cost of washing, which is considerable (at least 6*d.* per ton, but reaching at times, with the extra handling, as much as 2*s.* 6*d.* per ton), the expense of drying has also to be taken into account.

The coating of sea-salts around the grains of dune- and shore-sands does not appear to be objectionable for glass-making (as it is when such sands are used for concrete or for building-purposes), similar salts being added in the batch. The sands have the advantage of being well-graded (see Table V., page 165) as a result of repeated sorting by wind and water, but since their colour is not good and they often contain abundant shell-fragments, it is clear that repeated washing will not produce purity without the intervention of living organisms and percolation of water (*cf.*, for example, the patchiness of colour in the red sands of the Permian and Trias due to reduction around organic remains).

The value and importance of washing must be strongly emphasized. It is satisfactory to note that the producers of sand are now becoming alive, under war-conditions, to the improvement thus effected in sands and the correspondingly enhanced market value. Sands for refractory purposes, as well as glass-making, are now being washed in many instances by the producers. Although the process is frequently carried out at the sand-quarries, water is not always available in the quantities desirable. It will often pay glass-manufacturers to wash or re-wash their sand at the works, as dirt, dust, etc., are usually picked up during transit. The effect of washing is two-fold. It removes much adherent iron oxide, calcareous material, etc., and also clay, silt, and fine sandy matter which are undesirable in a glass-sand. A comparison of analyses of glass-sands before and after washing is of considerable value. Improvement will be noted in both grading and chemical composition. (See Tables on next page.)

In this connexion, as indicating the material washed out of a glass-sand, it is of interest to quote the following analysis from the remarks upon American Glass-sands in Bulletin 285 of the United States Geological Survey (page 461) :—

Analysis of a Slime from washings of a sand from Ottawa, Ill.

SiO_2	87·21 per cent.
Al_2O_3	7·50
Fe_2O_3	0·52
CaO	none
MgO	none
K_2O, Na_2O	0·20
Total	95·43 per cent.

Remainder mainly water.

This analysis indicates that besides ferruginous and clayey matter, much fine silica had also been removed from the sand.

TABLES SHOWING THE EFFECT OF WASHING UPON GLASS-SANDS.

A. *Mechanical Analyses.*

		VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade: >0·1 mm.
Coolkeeragh	Untreated.		7·1 %	75·9 %	7·5 %	3·0 %	6·5 %	90·5 %
,,	Washed.	1·1 %	2·7	90·4	4·6	0·5	0·7	98·8
Shirdley Hill	Untreated.		3·1	85·7	9·1	1·3	0·8	97·9
,, ,,	Washed.		1·3	84·5	13·1	0·2	0·9	98·9
Port-a-cloy	Untreated.		2·6	55·6	29·8	8·1	3·9	88·0
,, ,,	Washed.			49·7	44·7	4·5	1·1	94·4
Huttons Ambo	Untreated.		4·4	71·1	20·0	1·6	2·9	95·5
,, ,,	Washed.		1·2	91·9	5·6	0·5	0·8	98·7
Lynn	Untreated.		0·5	95·1	2·7	0·8	0·9	98·3
,,	Double washed.			90·8	8·7	0·2	0·3	99·5

B. *Chemical Analyses.* Iron-content only (as Fe_2O_3).

	Before washing.	After washing.
Port-a-cloy Silica	1·82	0·09 per cent.
Leighton Buzzard Sand, 1078 u	0·14	0·09
Huttons Ambo Sand (Anal. C. J. Peddle)	0·18	0·04
,, ,, ,, (Anal. H. F. Harwood).	0·13	0·04
Lynn Sand	0·11	0·03
Rainford Sand	0·05	0·03

A method of washing sand adopted abroad is on the principle of acid-scrubbers, the sand being arranged upon tiers of platforms, above one another and washed by distributed descending sprays of water.

Various methods, including tank-washing, have been adopted in this country, but some form of rotary process is most commonly used.

In some cases the sand is washed twice over to ensure better cleansing. It is often an advantage, especially when washing is adopted in order to cleanse a sand from iron oxide, to have the cylinder much longer than it usually is. Care should be taken to ensure that rotary washing-plant is suited to the grade of the sand. If the latter is too fine for the apparatus, much loss will result owing to the carrying off of fine sand in the stream of dirty water.

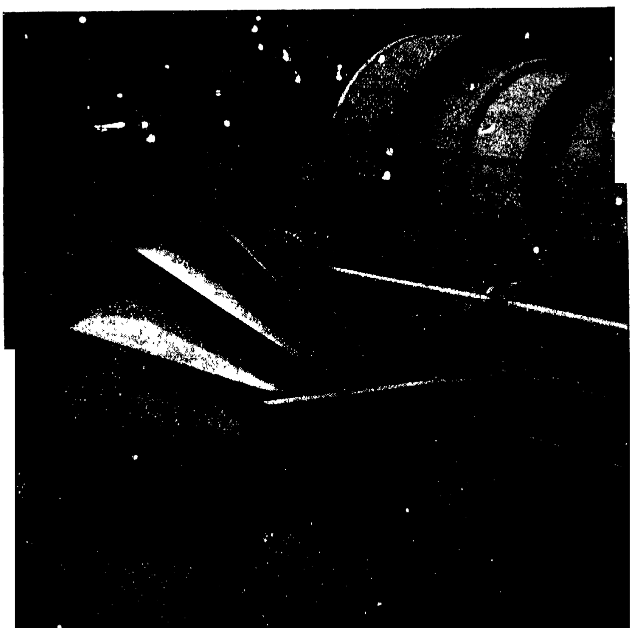
The most efficient machine for washing sand at present in use in this country is, in the writer's experience, that devised by Mr. O. Rikof of 159 Pentonville Rd, London, N. 1. A short description may be of use to sand-merchants and glass-manufacturers.

The Washing and Screening Machine (Rikof's Patent) is illustrated in Plate VII. and Fig. 13, and is so designed that it will, with small modifications to suit particular cases, wash any material from coarse gravel to fine sand. By an automatic feeding device the material is delivered into the slightly inclined revolving washing cylinder, the feeding being continuous and uniform so that all the materials are subjected to an equal amount of washing. The machine can therefore be run at maximum output without incurring the risk of temporarily overtaxing its capacity, which might happen in the case of manual feeding.

The length of the washing cylinder is fixed in accordance with the time required by the water for removing the binding materials and for separating the particles from each other. The cylinder is divided into sections or compartments so arranged that while the washing water overflows from a cleaner compartment into one containing dirtier material, and is finally discharged at the higher end of the cylinder, the material travels in the opposite direction and is automatically propelled over the partitions, each time into a compartment containing cleaner water. Eventually the materials are delivered into cylindrical screens, the number and fineness of which depend on the grades into which the said materials are to be divided. The screens are arranged concentrically, the innermost cylinder having the largest holes. The holes in the outermost cylinder determine the largest grains of the finest sand. Water-sprays between the screens facilitate the screening and subject the particles to a final cleansing. The water is led away with the sand into a special sediment separator, which constitutes a novelty in sand-washing machines and is necessary for securing clean, drained, sand (Fig. 13). This contrivance is most simple in construction as well as in working. It consists of a steel cone fixed at its larger end on to a wide flange centred

on an almost horizontal slowly revolving shaft. On the outside of this cone are numerous vanes or blades forming pockets for receiving the washed sand and the cleansing water. The pockets are so arranged that the top edge of each is level when reaching the horizontal plane containing the cone axis, and in this position it cuts off the supply of water and sand, which then goes into the next pocket. The contents, which during the filling are most vigorously agitated, become calm after the supply has ceased; and

Fig. 13.—*Cone-attachment to Rikof's Washing Machine, for cleansing and draining Sand.*



the sand settles quickly in the lower portion of the pocket near the flange, the water with the silt in suspension being gradually tilted off at the smaller end of the cone as the latter revolves and the larger end of the pocket is elevated over the top of the cone. When farther advanced, the sand is discharged at the other side of the cone, and the empty pocket proceeds on its way to receive a new charge.

The efficiency of the machine is dependent on its being worked at the proper speed and with a water-supply suiting the nature of the materials under treatment. Once carefully studied, however,

and properly adjusted, the machine works automatically and with excellent results.

The arrangement described above for draining the sand renders the question of drying it a much less serious matter. Air-drying is usually effective and sufficient. The users of sand naturally prefer it to be delivered in a dry condition, but methods of artificial drying are frequently too expensive for the sand-merchant to undertake. The transport of perfectly dry sand is also at times a troublesome matter.

Other devices are employed to hasten the drying by draining off the water, and sometimes the process is carried out in large ovens (two tons at a time), but systematic drying-plant like that used in America has not yet been introduced. Drying is carried out in the Mississippi valley and other places by the use of tier dryers, rotary methods, or steam coils. Small quantities of dry sand are frequently required in this country during the winter, for use as parting-sand in facing moulds for brick-making, etc. In this case a small oven is built of bricks, a fire lighted within it, and the sand heaped over and around the oven.

(b) *Screening, etc.*—In the matter of the improvement of the grade of a sand, screening may be combined with washing without much difficulty, and clayey and silty materials may be washed out by suitably controlled streams of water. If an elutriator is set up in the works' laboratory, analysis of the sand or crushed rock will give an indication of the velocity of the stream of water which will carry off all grades below that desired. For certain glasses it is not too expensive to treat local sands on a large scale in water-currents adjusted to this determined velocity. The process, in addition, will clean the sand of dirt and possibly some iron oxide. A velocity of 3·5 mm. per sec. (42 feet per hour) is the theoretical velocity which will carry away all particles (which can move freely) of diameter less than ·075 mm. The use of a greater velocity than this will be necessary on account of the friction of sluices, etc. and the bulk of sand treated. An air-blast may be used, as it is occasionally in engineering practice or for filtration purposes, to clear a sand of fine material. Such a blast of about 1·5 metres per second (about 4·9 feet per second) will carry off all particles of diameter less than 0·1 mm.

The importance of screening sands and crushed rocks to free them from coarse grains and fragments which would remain as undigested "seeds" or "stones" in the glass, has already been emphasized. It is frequently of value to fine-screen a glass-sand also. Mr. C. J. Peddle, chemist to Messrs. Wood Bros. Glass-Works of Barnsley, has demonstrated the improvement in the properties of glass-melts made from sands sifted to 80-mesh (0·22 mm.), the portion passing the screens being rejected. The reason for this is threefold. Clay and silt are removed as by washing. The surface-area of grains increases relatively as they decrease in diameter. The grains composing the fine grades of a

sand therefore tend to carry a relatively greater proportion of ferruginous and clayey coatings. In the third place, the proportion of heavy detrital minerals in a sand (including the objectionable zircon, rutile, and iron-bearing minerals) rises with decrease in grade-size. The following figures * illustrate this point:—

Heavy Minerals in Glass-Sands.

Variation with grade of percentage of crop having a density greater than 2·8.

	Grade-size in mm.			
	0·025–0·05.	0·05–0·1.	0·1–0·2.	0·2–0·4.
Park Lane, Reigate		·407 %	·098 %	·014 %
Ashurstwood	1·26	·253	·191	
Longdown		·302	·050	
Denford		·370	·230	
Jarvis Brook, Crowborough . .		·700	·060	·024 †
Tadmarton		·356	·098	·008

Dry-screening may be adopted to improve the grade and iron content of certain sands, where the coating of the quartz-grain consists of the valuable kaolin and not ferric oxide.

(c) *Burning.*—The better-class sands are undoubtedly improved by ignition. Water, often an objectionable constituent, is driven off. Organic substances are burnt out, and an improvement in whiteness results. Impurities which have been introduced during transit, *e.g.* dirt and coal (when the sand is brought back by coal-barges as ballast) are eliminated. For very special work, such as optical glass or the finest crystal ware, it is advisable to wash and burn even a very pure sand like that from Fontainebleau.

Burning, therefore, cleans a sand if it has been darkened by included peaty matter, but if the discoloration is due to staining by iron in a slight degree, the sand becomes a darker grey, brown, pink or red colour, the usual change being that from the hydrated oxide limonite, to the anhydrous oxide, hematite. The effect of burning thus yields in most cases a rough indication of the amount of iron present as staining, that in the heavy minerals, as already stated usually being of little importance. If the burning is carried on

* These are a selection from the results of a lengthy series of experiments which were carried out by my friend, Mr. V. C. Illing, M.A., F.G.S., of the Royal School of Mines (Imperial College of Science and Technology), and which he kindly permits me to quote.

† The heavy crop in the grade > 0·4 mm. diameter amounted to less than 0·001 per cent.

under standard conditions, the temperature being recorded by means of a pyrometer, and the increase in colour compared with the tint of known standard materials, an approximate idea of the amount of iron and organic matter present may be obtained. Most of the British deposits under consideration darken on heating, as do also the Belgian glass-sands so extensively used in this country. The latter are almost white, but attain a slightly pinker colour, while Dutch sand becomes greyer. Of the few British deposits which, like Fontainebleau sand, show no change on heating, the following may be mentioned: the best quality sand from Aylesbury and selected Godstone and Reigate sands (Lower Greensand), sand from Muckish Mountain, Co. Donegal, and a sand from Abergele, North Wales (the last two contain ferruginous patches which darken considerably). Pure white sandstones, such as the Coal-Measure Sandstone from Guiseley, near Leeds, also show no change of colour on heating.

Many glacial sands appear to be light-coloured and fairly pure, but on examination are usually found to contain limonite pellets (often representing decomposed iron-bearing minerals). They burn up to a much darker colour.

(d) *Chemical Methods.*—Other processes for the purification of sand from iron are too costly if any great quantity of the sand is required in industry.* Acids only partially clean the sands, even with application of heat. Hydrochloric acid has been used in this way, but the solution of iron oxide is never complete. By raising a mixture of a sand with about 2½ per cent of common salt to a red heat, and afterwards lixiviating with water, complete purification from iron is obtained.† Treatment with sodium hydrosulphide is said to yield the same result at lower temperatures. Nitre-cake has been successfully used on a small scale for dissolving out ferruginous and other compounds from sands. It consists of a mixture of acid and neutral sodium sulphates, its bleaching properties depending upon the unrecovered free sulphuric acid present. Nitre-cake has also been recommended for use in glass-making as a partial substitute for potash. A by-product from explosive works, it was obtainable before the outbreak of war for the mere carrying away from the tips, or for a nominal price of 1/- per ton. Since 1914 the demand for it has largely increased, owing to the unrecovered acid present, and the price is now about 17/- per ton at the works.

As an example of what can be done in the way of cleansing sand, the following analyses may be quoted. A yellow-brown

* The largest glass-making firms each use 100,000 to 150,000 tons of sand a year.

† Patent No. 8495 (1914) by J. G. A. Rhodin, "Improved Means for and Process of Bleaching Sand." The same idea was suggested in Bassett's patent for the extraction of potash from felspar, U.S. 1913 (see Potash Salts, U.S. G. S. Mineral Resources, 1913).

impure Triassic sandstone from Egglescliffe was treated with nitre-cake, and yielded a clean white sand :—

Before treatment	Fe_2O_3	0·20 per cent.
After treatment	Fe_2O_3	(*a*) 0·03, (*b*) 0·048 (*c*) 0·045 per cent.

Analysis of treated sand.

SiO_2	93·59 per cent.
Al_2O_3	3·51
Fe_2O_3	0·03
CaO	0·16
MgO	0·14
K_2O	0·94
Na_2O	0·83
Loss on ignition	0·66
Total	99·86 per cent.

This white sand does not change colour on burning.

The amount of alumina in this material is noteworthy. The product having been well screened and washed, several different-sized sands can be supplied. The products are well-graded, as the following mechanical analyses indicate :—

Sample	CS. >0·5 & <1 mm	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.
1	0·1	15·3	82·7	1·5	0·4	98·1 %
2			94·7	4·2	1·1	94·7

Material of rather coarser grade than this will also be available.

Sodium carbonate (washing soda) may also be employed for cleansing purposes, as the following figures of a sand from Leighton Buzzard indicate :—

Before treatment, Fe_2O_3, 0·04 per cent., after treatment, 0·015 per cent.

These methods are usually too costly except where pure sand is required for very special work, such as optical glass.

(e) *Magnetic Methods.*—Endeavours to remove objectionable heavy minerals from a sand are not, as a rule, paying propositions. Electromagnetic methods have, however, been applied in glass-works in the United States of America to the freeing of an otherwise suitable sand from such iron ores as magnetite. Separators have only been employed where high-class glass is made, and it is claimed that the colour and brilliancy are improved as a result of the treatment of the sand. Other iron-bearing minerals (including silicates, etc.) less permeable to electromagnetic action can at the same time be removed.

If hard rocks, such as well-cemented sandstones and quartzites,

are crushed for glass-purposes (see below), magnetic separation must be resorted to in order to free the product from fragments of iron or steel obtained from the rolls or jaws of the crushing-plant. The process is similar to that employed in the preparation of raw materials for the manufacture of pottery. It has not been found necessary to apply this treatment to sand obtained from soft grits and sandstones.

As an example illustrating the necessity of electromagnetic treatment of the product obtained by crushing a rock, the following may be mentioned:—

West of England China Stone & Clay Company.

China-stone crushed at Par, Cornwall:

Product before electromagnetic treatment: Iron estimated as Fe_2O_3,	0·12 p. c.
„ after	0·08 p. c.

About one cwt. of iron is abstracted weekly from about fifty tons of the crushed rock.

(For analysis of this china-stone, see page 120.)

The amount of ferruginous matter introduced by crushing rocks may be gauged from the following figures:—

Iron-content estimated as Fe_2O_3.

Westport Silica (vein-quartz from Achill I.):

before crushing, 0·004 per cent.; crushed product, 0·04 per cent.

Meldon Valley rock (aplite):

before crushing, 0·15 per cent.; crushed product, 0·27 per cent.

(f) *Grinding or Milling.*—Only for the best glasses for optical purposes is it advantageous, if at all, to grind the sand to a fine even state. Better mixing and more regular and rapid melting may thus be ensured, but the expense is considerable. The process has been adopted in the making of laboratory glass-ware, but it is doubtful whether any great advantage accrues. The procedure is not always followed in the making of optical glass (washed Fontainebleau sand being frequently used) or in the manufacture of the best "crystal" table-ware, although many of the authorities on glass-making are convinced that a better result is obtained by its adoption. At the same time many of those now engaged upon the manufacture of optical glass are not in favour even of grinding the batch. It is contended that air-bubbles are introduced in the fine material, and that "fining" (see page 38) is therefore more difficult to effect.

Crushing Strengths.—It is of considerable economic importance to know the crushing strength, *i. e.* the resistance to pressure before the rock breaks down, of the chief rocks which have been recommended as sources of silica and alumina for glass-making, and incidentally for refractory purposes.

The crushing strength of pegmatites is very similar to, but perhaps rather less than, that of granites, which varies from about 12,000 to 38,000 lbs. per square inch. An average figure is perhaps 18,000 lbs. per square inch.

Sandstones vary very much in their crushing strengths according to the degree of their consolidation and character of the matrix. A moderately soft sandstone from Plean, N.B., has a crushing-strength of 953 lbs. per square inch, while a finely-cemented quartzite may have a crushing strength of over 30,000 lbs. per square inch. Some sandstones used as building-stones give way at less than 3000 lbs. per square inch. Others withstand successfully a pressure of 16,000 lbs. per square inch.

The average crushing strengths of some of the rocks which have been crushed and put on the market as glass-sands or refractory materials are given in the following table. The tests were carried out in the Laboratories of the City and Guilds (Engineering) College (Imperial College of Science and Technology), with the kind co-operation of Prof E. F. D. Witchell, cubes of 2·5 ins. side being used, except where otherwise stated :—

Spital Sandstone	1,450	lbs.	per square	inch	(3-inch cubes)
Meldon Rock	24,100	,,	,,	,,	(3-inch cubes).
Stiper Quartzite	32,000	,,	,,	,,	
Appin Quartzite	32,200	,,	,,	,,	
Holyhead Quartzite	30,600	,,	,,	,,	

CHAPTER XI.

FOREIGN GLASS-SANDS.

A discussion of suitable British glass-sands would not be complete without comparative notes upon some widely-used Continental and American examples. Notes upon a few well-known foreign glass-sands are therefore appended.

EUROPEAN SAND

§ Lippe Sand.

This sand was imported into Britain before the war for the making of silica-ware and certain special varieties of glass; but its use was not extensive. Two different samples of this famous glass-sand from Dörentrup, Saxony, were supplied to the writer through the kindness of Dr. Walter Rosenhain, F.R.S., Director of the Metallurgical Department, National Physical Laboratory, Teddington, and were subjected to analysis and examination.

The sand occurs in deposits of Miocene age, and is associated with rafts of braunkohle *. In this connexion it may also be noted that the valuable glass-sand of Hohenbocka in Prussia, occurring in Miocene strata, is also associated with carbonaceous layers †.

Both samples of Lippe sand are beautifully white, of better colour even than that from Fontainebleau. The better sample is finer in grain and remarkably even, while the second is rather coarser. The chemical analyses are as follows:—

	I.	II.
SiO_2	99·88 per cent.	99·73 per cent.
Al_2O_3	0·18	0·20
Fe_2O_3 ‡	n.d.	n.d.
Loss on ignition	0·21	0·23
Totals	100·27 per cent.	100·16 per cent.

* Jahresb. niedersächs. geol. Ver. 1910, p. 185; and Zeitschr. deutsch. geol. Gesellsch. Band xl., 1888, p. 310.

† K. Keilhack, Jahrb. K.-preuss. geol. Landesanst. 1908, Band xxix. pt. ii. p. 214.

‡ Separate estimation of iron gave: I. 0·02 per cent., II. 0·03 per cent. Analyst: E. Spencer. These values are probably too high.

It is said that, such is the remarkable constancy of chemical purity, the sand is guaranteed when sold to contain 99·98 per cent. of silica.

The mechanical analysis of the finer and better sample is:

>0·5 & <1 mm., one or two grains; >0·25 & <0·5, 78·6 %; >0·1 <0·25, 19·9 %; >0·01 & <0·1, 0·4 %; <0·01, 1·1 %*. Total sand-grade: >0·1 & <1 mm., 98·5 %.

$$\left[\begin{matrix} CS & MS & FS & s & c & S \\ \text{tr.} & 78{\cdot}6 & 19{\cdot}9 & 0{\cdot}4 & 1{\cdot}1 ; & 98{\cdot}5 \end{matrix}\right]$$

Measurement under the microscope shows that the average diameter of the grains is 0·3 mm. (or perhaps slightly less). They are composed, with the exception of the few detrital minerals, of colourless clean quartz and a very little felspar, subangular to angular in shape. The mechanical analysis of the second sample is:

>0·5 & <1 mm., 10·2 %; >0·25 & <0·5, 85·8 %; >0·1 & <0·25, 1·4 %; >0·01 & <0·1, 1·0 %; <0·01, 1·6 %*. Total sand-grade >0·1 & <1 mm., 97·4 %.

$$\left[\begin{matrix} CS & MS & FS & s & c & S \\ 10{\cdot}2 & 85{\cdot}8 & 1{\cdot}4 & 1{\cdot}0 & 1{\cdot}6 ; & 97{\cdot}4 \end{matrix}\right]$$

The grains, which are subangular, are similar under the microscope, but are for the most part nearly 0·5 mm. in diameter.

The heavy residue of minerals was small in each case (less than 0·01 per cent. by weight), but, as is often the case, was greater in the finer sand than in the coarser.

The former yielded a pretty residue consisting of abundant zircon and red-brown rutile, rather rounded, and averaging 0·12 mm. diameter, together with large kyanite fragments up to 0·7 mm. long, and coarse staurolite and tourmaline grains. The staurolite is deep golden-brown in colour, of diameter 0·2 to 0·3 mm. The tourmaline occurs in grains up to 0·3 mm. diameter, of brown, greyish, greenish blue, and deep blue colour. Magnetite, ilmenite, leucoxene (0·2 to 0·3 mm. diameter), and limonite occur. Small and non-pleochroic dusky grains of andalusite occur less commonly, and chlorite also was seen.

The second sample yielded a rather coarser residue, consisting of abundant pleochroic andalusite (0·3 mm. diam.), large, yellow, grey-brown, and greenish tourmaline (0·3 mm. diam.), deep green hornblende (0·2 mm. long), and ilmenite. Staurolite and zircon occurred in small grains 0·05 mm. long. Chalcedony was also seen in the sand.

* Hygroscopic water included.

§ Fontainebleau Sand.

The sand, of Upper Oligocene (Stampian) age and associated with lignites *, occurs in considerable quantities at Fontainebleau, near Paris.

The mechanical and chemical composition are given in the Tables, and the general properties are discussed in Chapter V.

The sand costs upon delivery at British works from 12*s.* to 39*s.* per ton (rising to 50*s.* and 60*s.* through war-difficulties), according to distance brought on rail, an average price being 17*s.* The cost has, of course, increased owing to the war; and for some time after the outbreak of war, as well as again at the time of writing, difficulties existed, due to shortage of labour and ships, in getting it through to England and Scotland.

§ Belgian Sand.

The sands cost, upon delivery in this country, from 4*s.* to 16*s.* per ton. They often arrive as ballast, packing for bottles, etc. Large quantities were sent from the Campine.

Some of the sands are shipped from Rotterdam, and the unequal quality since the outbreak of war leads to the suspicion that some of those now being supplied may be inferior Dutch sands. Much variability in tint and slight differences in mechanical composition occur (see Tables, pages 166, 167, and Fig. 10, page 50). The sands may be almost white, a very pale grey, or a marked pale pink, in part due to the presence of pink quartz. Their iron-content is slightly greater than that of Fontainebleau sand, and they burn to a rather darker pink shade. Washing does not improve the colour noticeably.

One sample from Barnsley Glass-works, which was analysed, proved to have the following chemical composition :—

SiO_2	99·38 per cent.
Al_2O_3	0·30
Fe_2O_3 ..	0·02
Loss on ignition ..	0·23
Total ..	99·93 per cent.

Mechanical analyses show the following grade-proportions :—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·01.	S. Total sand-grade: >0·1 & <1 mm.
Knottingley Glass-works.	9·6 %	83·3 %	5·9 %	1·2 %	0·0 %	98·8 %
Barnsley Glass-works	<0·1	99·3	0·3	0·4	0·0	99·6

* "Revision de la Feuille de Fontainebleau," Bull. Serv. Carte géol. France, No. 122, vol. xix. (1909) p. 9; and numerous other references.

Quartz, somewhat rounded to subangular, makes up the bulk of the sand, but cleavage-flakes of felspar are to be seen. The heavy residue is small, and of the type which in Britain characterizes the Pliocene deposits. Among the coarse dense grains are kyanite, andalusite, staurolite, rutile, yellow-brown tourmaline, iron ores, etc.

§ Dutch Sand.

The prices of Dutch sand have varied considerably in pre-war and present times, the range being from 9*s*. to 23*s*. per ton.

Only a few samples have been analysed. They had a slight grey or brown colour, some darker than Belgian sand, and differed to some extent in grade-percentage (see Tables, pages 166, 167, and Fig. 10, page 50). Occasionally the sand is white and equal in quality to that from Fontainebleau.

The chemical analyses of two samples are as follows:—

	Knottingley Glass-works.	Edinburgh & Leith Glass-works.
SiO_2	99·23 per cent.	99·63 per cent.
Al_2O_3	0·50	0·35
Fe_2O_3	0·02	0·03
CaO	n. d.	0·08
MgO	n. d.	trace
Loss on ignition	0·22	0·19
Totals	99·97 per cent.	100·28 per cent.

The grading composition is indicated by the following results of mechanical analyses:—

	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5.	FS. >0·1 & <0·25.	s. >0·01 & <0·1.	c. <0·1.	S. Total sand-grade >0·1 mm.
Knottingley Glass-works.	0·7 %	68·0 %	30·8 %	0·5 %	0·0 %	99·5 %
York Glass-works	0·4	93·5	4·8	1·3	0·0	98·7

The heavy crop is a rich and abundant one, consisting of well-rounded grains 0·15 to 0·2 mm. diameter. The minerals present, besides quartz and felspar, include purple and brown tourmaline, epidote, staurolite, kyanite, red garnet, green hornblende, zircon, andalusite, muscovite, ilmenite and leucoxene, magnetite, limonite, etc.

American High-Grade Glass-Sands

For the samples of sands upon which the following descriptions are based, the writer is indebted to Dr. G. Otis Smith, the Director of the United States Geological Survey.

The beauty and high quality of the best American glassware have long been known to those concerned with the industry in Britain. It may therefore be of interest to give a brief description of the best glass-sands produced in the United States. The samples were collected by Mr. Ralph W. Stone, whose valuable accounts of the American glass-sands and their treatment have been of great use to British workers. For additional information, therefore, reference should be made to his descriptions of some of the sands in Bulletins 285 and 315 of the United States Geological Survey and to the Annual Reports on Mineral Resources (*e. g.*, 1911–15). The following notes are based upon examination of the samples supplied, but the accompanying letters from the sand-merchants have given information as to the treatment to which the materials have been subjected.

It will be observed that the crushing, screening, washing, and drying of the sands are more carefully and thoroughly carried out across the water than here. British glass-manufacturers will doubtless note this with interest, and endeavour to impress the fact upon the sand-merchant at home. We should remember, however, that the American quarrying and treatment are carried out upon a large scale and that greater facilities for transport appear to exist in the United States than in this country.

For comparison with British deposits, it is interesting to note that the glass-sands are obtained by the treatment of friable sandstones, all of which are of considerable geological age. They range from Cambrian quartzite to Carboniferous sandstone. Similar materials have been recommended from these islands, and the writer has dealt elsewhere with such resources. It is interesting to note, however, that all the best West European glass-sands, including many of those from the British Isles, come from geological deposits of Tertiary age, *i. e.*, are comparatively recent in formation.

The fact that practically no compound grains are present in these American glass-sands points to friability of material and care in treatment. All are highly quartzose and none very aluminous in character. The alkalies have not been estimated, since in most cases they are either absent or exceedingly small in amount †. The mineral-content in all the sands is small, and the few detrital minerals are mostly of the common, very stable, type. The iron-content throughout is remarkably uniform and low,

* This account is reprinted with slight modifications from the 'Transactions of the Society of Glass Technology,' vol. i. (1917) p. 147, by permission of the Council of the Society.

† All the analyses have been made upon the treated samples as received.

namely, about 0·02 per cent.. In some of the sands, such as those from the St. Peter's sandstone, the very pure appearance of the sand would lead the observer to expect a smaller percentage even than this. When the heavy minerals are examined, the reason is clear. In these cases, the iron-percentage is due to the authigenous *pyrite* (FeS_2) present. Most of the sands show no change of colour on ignition.

Sufficient material could not be spared for the purpose of working out the mineral composition of each sand exhaustively.

Sand from the Ottawa Silica Company, Ottawa, Illinois.

The sand is produced by crushing the very friable St. Peter's sandstone of Carboniferous age; the Company state that it has been washed twice, steam-dried, and screened. It is slightly greyish in colour, and consists of beautifully rounded grains, a few of which are spherical, most being spheroidal. The surfaces are in many cases roughened and etched. A few large grains occur.

The chemical analysis quoted by the Company is:—

SiO_2	99·82 per cent.
Al_2O_3 and Fe_2O_3	0·05
CaO and MgO	0·13
Total . .	100·00 per cent.

and that by Dr. Harwood and Mr. Eldridge:—

SiO_2	99·48 per cent.
Al_2O_3	0·16
Fe_2O_3 .	0·02
CaO . .	0·11
MgO . .	0·05
Loss on ignition ...	0·13
Total	99·95 per cent.

The mechanical analysis is as follows:—

>1 mm., 0·5 %; > 0·5 & <1 mm., 21·6 %; > 0·25 & < 0·5, 75·6 %; > 0·1 & < 0·25, 1·3 %; > 0·01 & < 0·1, 0·3 %; < 0·01, 0·7 %. Total sand-grade, >0·1 mm., 99·0 %.

$$\left[\frac{\text{VCS}}{0\cdot5}, \frac{\text{CS}}{21\cdot6}, \frac{\text{MS}}{75\cdot6}, \frac{\text{FS}}{1\cdot3}, \frac{\text{s}}{0\cdot3}, \frac{\text{c}}{0\cdot7}; \frac{\text{S}}{99\cdot0}\right]$$

The heavy detrital minerals are small in quantity (0·02 per cent.) and of little interest. Many are well-rounded, blue and brown tourmaline, zircon, and large garnets (0·2 mm. diameter) being notable. Pyrite with excellent crystal form is abundant, and is undoubtedly authigenous, that is, has been produced since the deposition of the sandstone. It has suffered no abrasion. Its

presence probably accounts for the 0·02 per cent. of Fe_2O_3 indicated in the analysis, an amount larger than the appearance of the sand would lead us to expect.

Sand from the Wedron Silica Company, Ottawa, Illinois.

This sand is of the same age as the last, and is stated by the Company to be washed twice, thoroughly dried, and screened. It is a beautifully white, clean sand, composed of perfectly rounded grains (Plate V. fig. 2). The description of the Ottawa Silica Company's sand applies to this sand also.

Dr. Harwood's chemical analysis is as follows:—

SiO_2 . .	99·58 per cent.
Al_2O_3	0·12
Fe_2O_3	0·02
CaO	0·13
MgO .	trace
Loss on ignition .	0·17
Total	100·02 per cent.

The mechanical analysis indicates:—

> 0·5 & < 1 mm., 6·1 %; > 0·25 & < 0·5, 88·4 %; > 0·1 & < 0·25, 5·1 %; >0·01 & < 0·1, 0·2 %; < 0·01, 0·2 %. Total sand-grade, >0·1 mm., 99·6 %.

$$\left[\frac{CS}{6\cdot1}, \frac{MS}{88\cdot4}, \frac{FS}{5\cdot1}, \frac{s}{0\cdot2}, \frac{c}{0\cdot2}; \frac{S}{99\cdot6}.\right]$$

The heavy detrital minerals, as before, are highly rounded, averaging 0·12 mm. diameter. The pyrite, which is again abundant, is clearly not detrital.

Sand from the Berkshire Glass-Sand Company, Cheshire, Mass.

The sand is produced from a crushed Cambrian quartzite. The Company state that it is washed three times and passed through a 40-mesh brass wire-screen. An average sample of the sand taken from the quarry (and therefore unwashed) by Mr. H. C. Demming, who was investigating silica-sands for filtration-plant, had a composition as follows:—

Silica	99·28 per cent.
Alumina	0·49
Iron oxide	0·34
Lime . ..	0·12
Magnesia	0·003
Phosphorus oxide .. .	0·0047
Sodium and Potassium oxides ..	0·38
Sulphur	0·0096
Organic matter and loss	0·17
Total	100·7973 per cent.

Dr. Harwood's analysis of the washed sample supplied is :—

SiO_2	99·00 per cent.
Al_2O_3	0·30
Fe_2O_3	0·03
CaO	0·15
MgO	none
Loss on ignition	0·21
Total	99·69 per cent.

A mechanical analysis gave the following information :—

>0·5 mm., none ; >0·25 & <0·5, 76·6 % ; >0·1 & <0·25, 21·3 % ; >0·01 & <0·1, 0·3 % ; <0·01, 1·8 %. Total sand-grade, >0·1 mm., 97·9 %.

$$\left[\frac{MS}{76\cdot6},\ \frac{FS}{21\cdot3},\ \frac{s}{0\cdot5},\ \frac{c}{1\cdot8};\ \frac{S}{97\cdot9}\right]$$

The sand is rather fine-grained, sugary to the touch, and fairly angular. The detrital mineral assemblage is greater in amount (0·04 per cent.) and more interesting than that of the Illinois sands. Much limonitic matter occurs, and muscovite mica, chlorite, green hornblende, tourmaline, and zircon are also present. The sand is widely used for the finest cut-glass.

Sand from the Berkeley Glass-Sand Company, Berkeley Springs, W. Va.

This sand is the well-known high-grade deposit from Berkeley Springs, used so largely for table-glass and the best ware. It is produced by crushing the Oriskany sandstone of Silurian age. After being crushed, it is sent through a wet screen, then steam-dried, and, finally, once more screened. It is kept in concrete storage-bins of about 1500 tons capacity, the daily production being about 400 tons.

The chemical analysis indicates (H. F. H. and A. A. E.) :—

SiO_2	99·65 per cent.
Al_2O_3	0·11
Fe_2O_3	0·02
CaO	0·12
MgO	trace
Loss on ignition	0·23
Total	100·13 per cent.

The mechanical composition is as follows :—

>0·5 & < 1 mm., 1·5 %; > 0·25 & < 0·5, 97·1 %; > 0·1 & < 0·25, 0·8 % >0·01 & < 0·1, 0·2 %; <0·01, 0·4 %. Total sand-grade, >0·1 mm., 99·4 %.

$$\left[\frac{CS}{1\cdot5},\ \frac{MS}{97\cdot1},\ \frac{FS}{0\cdot8},\ \frac{s}{0\cdot2},\ \frac{c}{0\cdot4};\ \frac{S}{99\cdot4}\right]$$

The sand is pure white and consists of somewhat irregul[ar] grains (Plate V. fig. 1). The detrital mineral percentage is small (0·01 per cent.), and is of the usual type.

Sand from the Juniata White Sand Company, Hanover St., Baltimore, Maryland.

The quarry of the Juniata Sand Company is at Mapleton, Pa., and is also in the Oriskany sandstone. The rock is crushed, and is said to go through five washings and three screenings.

Dr. Harwood's analysis is as follows :—

SiO_2	99·33 per cent.
Al_2O_3	0·16
Fe_2O_3	0·02
CaO	0·15
MgO	0·11
Loss on ignition	0·20
Total	99·97 per cent.

The mechanical analysis yields the following information as to grades :—

>1 mm., 1·6 %; $>0·5$ & <1 mm., 11·2 %; $>0·25$ & $<0·5$, 85·7 %; $>0·1$ & $<0·25$, 0·4 %; $>0·01$ & $<0·1$, 0·1 %; $<0·01$, 1·0 %. Total sand-grade, $>0·1$ mm., 98·9 %.

$$\left[\frac{\text{VCS}}{1\cdot 6},\ \frac{\text{CS}}{11\cdot 2},\ \frac{\text{MS}}{85\cdot 7},\ \frac{\text{FS}}{0\cdot 4},\ \frac{\text{s}}{0\cdot 1},\ \frac{\text{c}}{1\cdot 0};\ \frac{\text{S}}{98\cdot 9}\right]$$

The sand is subangular, a few spherical grains only being seen. The detrital mineral percentage is small (0·02 per cent.), consisting largely of zircon, tourmaline (blue, green, and brown), ilmenite and leucoxene (0·2 mm. diameter), rutile, and blue anatase.

Sand from the Tavern Rock Sand Company, St. Louis.

This glass-sand is produced by crushing the friable St. Peter's sandstone of Carboniferous age. The Company do not wash any sand, but crush, dry, and screen once. The quarries are at Pacific, Mo.

Dr. Harwood's analysis is as follows :—

SiO_2	99·03 per cent.
Al_2O_3	0·23
Fe_2O_3	0·02
CaO	0·21
MgO	0·05
Loss on ignition	0·35
Total	99·89 per cent.

The composition as given by the Company is :—

SiO_2	99·97 per cent.
Al_2O_3, Fe_2O_3, CaO	0·03
Total	100·00 per cent.

For an unwashed sand, the silica-content is very high and the iron-percentage very low.

The mechanical analysis is :—

>1 mm., a few compound grains; >0·5 & <1 mm., 2·7 %; >0·25 & <0·5, 90·1 %; >0·1 & <0·25, 6·1 %; >0·01 & <0·1, 0·5 %; <0·01, 0·6 %.
Total sand-grade, >0·1 mm., 98·9 %.

$$\begin{bmatrix} VCS & CS & MS & FS & s & c & S \\ tr. & 2{\cdot}7 & 90{\cdot}1 & 6{\cdot}1 & 0{\cdot}5 & 0{\cdot}6 & 98{\cdot}9 \end{bmatrix}$$

The sand is fairly well rounded, but not very clean. The percentage of detrital minerals is low (0·01 per cent.) and the suite consists chiefly of zircon, tourmaline, ilmenite, and leucoxene (0·5 mm. diameter)

COLONIAL GLASS-SANDS.

Chemical and Mechanical Analyses of several glass-sands from India and Australia are given in the Tables on pages 154, 157, and 165. Of these, the Jubbulpore sand is that used in the well-known Allahabad Glass-works, while for the remainder of the samples the writer is indebted to the respective Directors of the Geological Surveys of India and Victoria. There is little doubt that the Colonies can supply their own needs in this direction; the sands examined by the writer have all been of good quality.

CHAPTER XII.

LOCATION OF BRITISH SUPPLIES OF GLASS-SANDS.

General Geological Considerations.

With the view of realizing the geological conditions under which glass-sands occur, it is instructive to draw attention to several salient facts, in order the better to search for suitable supplies. The association of pure white sands with carbonaceous matter has frequently been mentioned in this Memoir. Indeed, it may be said that every example of the better-class glass-sands in Europe indicates that the deposit is associated with vegetable matter. Lippe sand occurs with rafts of braunkohle. Hohenbocka sand is associated with carbonaceous layers; Fontainebleau sand with lignites; and Aylesbury and Leighton sands with peaty layers. Some of our purest sandstones occur in the Coal Measures, and, of second-rate sands, the Headon Hill and Bagshot Sands of the Isle of Wight (Alum Bay, Whitecliff Bay, etc.), Dorset, and elsewhere are interbedded with lignites; while the white beds of the Northampton Sands (Inferior Oolite) and the Estuarine Series in Yorkshire are found in deposits carrying plant-remains. The well-known Brora coal in the Jurassic of north-east Scotland is associated with white sandstones. The purest Ashdown Sands (Wealden) often carry plant-remains. The glacial sands of Lancashire, used for the making of window-glass, owe their low percentage of iron to the association with peaty material.

The bleaching of red and yellow sands for a few feet in depth on heaths and by the action of peat are other examples of this phenomenon. The explanation appears to lie in the reducing action of the vegetable matter. Ferric compounds are reduced to the ferrous state, and are often carried off in solution by percolating water. Sometimes, however, they remain and are revealed by the return of the red colour on burning.

Estuarine or lagoon conditions favour the formation of white sands and sandstones. In our search for glass-sands, particularly in the Colonies, we have therefore a valuable indication of the kind of strata in which to look (that is, beds containing coal, lignites, peaty matter, etc.) and the conditions under which we may expect deposition of the required material to have occurred. Simplicity of composition and perfection of grading are more likely to be found in deposits of late geological age, as exemplified by the occurrence of glass-sands in Western Europe. It is very improbable that any new and large British supplies of first-class glass-sands will be revealed; but, in addition to the extension of supplies now being

exploited, deposits of small extent, at present unknown, probably occur in many cases in proximity to, or along the outcrops of, strata previously worked.

Location of British Supplies of Glass-Sands.

(a) *England.*—Considered stratigraphically (that is, according to geological age), the chief localities for English supplies, with their corresponding geological horizons, may be detailed as follows :—

Recent (blown & shore) Sands.		*Passim.*
Glacial.		Crank, Rainford, etc. (Lancs).
Deposits of Doubtful Age (pre-Glacial).		Parsley Hay (Derbyshire). Brassington (Derbyshire). Low Moor (Derbyshire). Ribden (Staffs). Abergele (Denbighshire). Rhes y cae (Flintshire), etc.
Upper Eocene.	Headon Hill Sands. Barton Sands.	Alum Bay, I. of Wight, etc. Fordingbridge (Hants). Longdown, New Forest.
Lower Eocene.	Thanet Beds.	Charlton (Kent). Rochester (Kent).
Lower Cretaceous.	Lower Greensand.	Aylesbury (Bucks). Aylesford (Kent). Blackgang Chine (I. of W.). Godstone (Surrey). Hollingbourne & Bearsted (Kent). Leighton Buzzard (Beds). Lynn (Norfolk). Oxted (Surrey). Reigate (Surrey).
	Tunbridge Wells Sands. Ashdown Sands.	Ashurstwood (Sussex). Fairlight (Sussex). Bulverhyth (Sussex).
Middle Oolites.	Kelloway Beds.	Burythorpe (Yorks). South Cave (Yorks).
Lower Oolites.	Upper Estuarine Beds. Lower Estuarine Beds.	Huttons Ambo (Yorks). Corby, etc. (Northants). Denford (Northants).
Upper Trias.	Keuper Waterstones.	Spital (Cheshire). Alderley Edge (Cheshire).
Lower Trias.	Lower Bunter Sands.	Worksop (Notts)
Carboniferous.	Coal Measures.	Guiseley (Yorks).
	Carboniferous Limestone.	Mold (Flintshire). Minera (Denbighshire).
Lower Ordovician.	Arenig.	Stiperstones (Shropshire).

Most of these localities and geological horizons are marked upon the map, Plate VIII. The outcrop of each formation is shown, in order that the direction of the possible extension of glass-sand resources may be indicated. Take, for example, the deposit known as the Lower Greensand, from which so many of our best glass-sands

are obtained. The bed is worked for glass-making at Lynn, Leighton Buzzard, Aylesbury, and Aylesford; it was formerly worked at Reigate, Godstone, Hollingbourne, and in the Isle of Wight. Many of these localities are marked upon the map, and will be seen to be distributed over the outcrop of the bed. The area marked by the outcrop is therefore that over which extension of the supplies may be expected, and which should be explored for the purpose. Another important horizon is that of the Inferior Oolite (and in Yorkshire, of the Middle Oolites also). The beds are frequently variable in this series of deposits, but investigation of the outcrop will doubtless reveal extensions or new deposits of the glass-sands.

The Tunbridge Wells Sands and the Ashdown Sands of the Wealden area yield important supplies of pure sand. The resources have not been properly explored, and are certainly great. Unfortunately, the localities where they are at present worked are not well situated for transport.

The Triassic System rarely yields sands pure enough for glass-making, and when such are found the best glass-ware which can be made from them is the class of work exemplified by pale bottles. The Bunter Sands of Worksop, the Keuper Sandstone of Spital, Cheshire, and possibly the similar rock at Alderley Edge, are deposits of this character, the first two being fortunately situated near to coalfields.

We may classify these localities broadly according to the kind of glass for which the sand may be used. Obviously the limits will not be easy to define, and moreover, as mentioned in the Preface, and also on page 151, with the advance of chemical research upon glass, the latitude permitted in the composition of sands for certain glasses is increasing.

The shore- and dune-sands occurring around our coasts are never sufficiently pure for making other than common bottle-glass. The Glacial Sand from Rainford, Crank, and Shirdley Hill in Lancashire is used (after washing) for the making of window-glass and for bottles. The Eocene sands mentioned from the Hampshire Basin have at present been used only for better-class bottle-making, but, especially if they are washed, would be of value for such better qualities as lighting-glass, laboratory-ware, etc. The Thanet Sands from Kent are utilized for bottle-making only. Highly siliceous sands, but less pure and more indurated than those from the Lower Greensand occur in the Upper Greensand over a wide area from the Isle of Wight to Wiltshire and Kent. Of the Lower Greensand deposits, Aylesbury sand can be used for the manufacture of optical glass, table-glass, chemical and pharmaceutical apparatus, and many other varieties. Leighton and Lynn sands are successfully employed for lighting-glass of all descriptions (electric-globes, chimneys, etc.), for laboratory-ware, flint-bottles, pressed-ware, etc. Aylesford sand at present goes only to bottle-making areas, but like the sand from Reigate, could be successfully used for better kinds of glass. The Tunbridge Wells Sands and Ashdown Sands

mentioned as occurring in Sussex, are not at present worked for glass purposes, but as their analyses indicate (see pages 52–54) they will be of service for much good glass-ware, if economic considerations permit their exploitation.

The English Jurassic strata are very variable, and it is possible that sands of great purity not known to us at present may turn up, but their thickness and extent must be limited. The Corallian Beds often contain clayey or calcareous sands, and the Portland Sands are too grey or brown and impure for glass-making.

The Kelloway Beds of Burythorpe and South Cave in Yorkshire are of great value for the bottle industry of that county, and with washing could be utilized for window-glass, lighting-glass, etc. The Estuarine Sands from Huttons Ambo, when washed, are suitable for the manufacture of all qualities of glass, even up to certain optical varieties. Unwashed, they would serve for bottle-making, when the alumina they contain would be of much value on account of its strengthening properties.

The Inferior Oolite "Sands" of the western area (Dorset Coast, Bridport, Yeovil, Midford, Wotton, Cotteswolds, Cheltenham, etc.) are too ferruginous and are occasionally calcareous. In the Northampton Sands and Estuarine Series, beds of whitish sand occur, but are usually calcareous and never very pure. The detrital mineral percentage is also high. Sands are said to have been worked for glass-making about 1860 from Wansford, Apethorpe, Blatherwyke, Burleigh, Caswick, etc.; but the glass cannot have been of good quality. Analyses of sands from Corby, Denford, etc., will be found in the Tables. The Estuarine Sands of the Midlands are difficult to work owing to their variability, and are rather fine in grain. Their suitability may be determined from their analyses (pages 69, 156, and 162).

The Triassic sands are usually only of value for bottle-making, when their alumina-content is a distinct advantage. They are not sufficiently well-graded, nor are they very pure. Washing may improve the Spital sand sufficiently to render it of value for better-class glass.

The Lower Permian Yellow Sands are often incoherent, but are too deeply iron-stained and calcareous all along their outcrop to be of service.

The Carboniferous Period was one in which very pure sandstones were laid down, the association with much organic matter being here noteworthy. The decomposition of pure sandstones (*e. g.*, in Ireland, near Glasgow, in Yorkshire, etc.) has given suitable sands, and some very good examples have been found. Such rocks are often crushed and washed before being put upon the market. In some pale-coloured sandstones the cement is barytes (often derived from Permian deposits above), when crushing hardly pays. Nothing suitable seems to occur, nor would it be expected, in Devonian strata.

Incoherent glass-sands are not to be expected from Archæan and Palæozoic rocks. Very pure quartzites occur, but the objections

to crushed rocks (see page 80) and the question of expense almost rule them out. Where very pure rocks have rotted *in situ* and been exposed to washing by rain, etc., glass-sands may be produced. The whitish Cambrian quartzites of the Midlands are not sufficiently pure. Other Cambrian sandstones are less pure still, and the same objection applies to Ordovician and Silurian Rocks.

The high alumina-bearing deposits of Derbyshire and Staffordshire (Parsley Hay, Newhaven, Longcliffe, Ribden, etc.) are of very great value for refractory purposes, and so far as glass-making goes, may be of importance for resistance-glasses such as those required in the making of thermometers, ampoules, combustion-tubing, etc., as well as for certain varieties of optical glass.

(b) *Scotland.*—The Scottish deposits fall into two well-marked groups. In the first group, and of little importance, are the dune- and shore-sands worked for bottle-making. Those from Jura and Islay are pure enough for better quality glass. In the second group are the white, grey, or pale brown, soft and decomposed sandstones of the Carboniferous System, which have been crushed and treated to provide "sands" for refractory purposes and glass-making. Such are the deposits belonging to the Millstone Grit, Carboniferous Limestone Series, and Calciferous Sandstone Series from Caldwell, Glenboig, Hailes, Kilwinning, Kingscavil, Levenseat, and Plean. Of these, the best are the Levenseat, Caldwell, and Kilwinning materials. The deposits are at present utilized for low-grade glass-work only.

Many of the pre-Cambrian quartzites (*e. g.* Jura, Islay, Appin, Killiecrankie, etc.) seem to be pure enough to crush as sources of silica for glass-making and furnace purposes. The expense involved in the crushing and subsequent treatment is, however, prohibitive.

It is possible, though unlikely, that the pale-grey sandstone of Brora (Middle Oolites) will be worked for glass-purposes, although a low-grade fuel is close at hand.

The glass-sand resources of Scotland (and also of Ireland) are thus much more limited than those of England. This is due to a geological fact—that of the absence or small development of those stratigraphical horizons such as the Inferior Oolite, Lower Greensand, Eocene, Miocene, and Oligocene, which carry the best glass-sands of Western Europe.

(c) *Ireland.*—The Irish supplies, in the same way, fall into two well-defined classes. Shore- and dune-sands, usually suitable for bottle-glass only, occur at Ardara (Co. Donegal), Ballycastle (Co. Antrim), Coalisland (Lough Neagh), the shores of the river Foyle, Millisle (Co. Down), Portrush (Co. Antrim), Rosslare (Co. Wicklow), Sandymount Strand near Dublin, Silver Strand near Wicklow), Sutton near Dublin, and other localities. The more valuable

"sands" are obtained from the decomposition or crushing of pre-Cambrian rocks from Muckish Mountain (Co. Donegal), Westport (actually from Achill Island), Port-a-cloy (Co. Mayo), Tinahely (Co. Wicklow), and other places, and of the sandstones of Carboniferous age from Ballycastle, Cookstown, and Coolkeeragh.

The best Irish material is undoubtedly that from Muckish Mountain, Co. Donegal. If the rock, which has already been described as a partially decomposed quartzite, is properly treated by crushing, screening, washing, and drying, much of it will be of service for the best optical glass and table-ware; the material generally will be of use for all qualities of glass.

The old Irish glass-industry, carried on at Ballycastle, Limerick, Cork, and Waterford among other places, was dependent upon sands from Alum Bay (Isle of Wight), Lynn, and Reigate.

Distribution of the Glass-making Industry in the British Isles.

The Maps (Plates IX. & X.) show the localization of the chief British glass-making areas *, and also indicate the localities where glass-sands are worked, the ports into which foreign sands are brought, and the coalfields. It is noteworthy that, with the exception of the London district, in which almost everything is bought, manufactured, or sold, the glass-making areas are situated upon, or very close to, the coalfields. The industry consumes a large quantity of fuel—either directly as coal, or indirectly as producer gas, etc., made from it. About a ton and a quarter of fuel are consumed for each ton of finished glass produced in tank-furnaces, and the consumption is greater in pot-furnaces. To yield a ton of finished glass about a ton and a third ot raw materials are required. Coal, as is well known, is much more bulky and troublesome to move than the same weight of such raw materials as sand, hence the location of the manufacture.

A general statement only is possible regarding the distribution of the various kinds of glass-manufacture.

Optical glass is made in the Birmingham and Derby areas. Table and decorative ware is manufactured in the Stourbridge area near Birmingham, and in Manchester. London, Glasgow, Warrington, and Tutbury also contribute a certain amount. The Stourbridge area (including Brierley Hill, Dudley, Walsall, etc.) has long been famous for its beautiful "crystal" ware, both on account of the quality of the glass and the artistic character of the work.

Scientific and technical glass is made in Edinburgh and Perth as well as the following localities notable for laboratory and

* The writer was able to make this analysis as a result of visits to most of the glass-works in the United Kingdom, and by using freely the excellent card-catalogue of British Glass-Manufacturers, compiled by the Board of Trade.

medical apparatus:—London, Leeds, Birmingham, Barnsley, Manchester, Dudley, and St. Helens. Gauge-glasses have been manufactured at St. Helens, Manchester, Birmingham, and Perth.

The manufacture of electric bulbs, etc. is now being carried on near and far, but possibly the following may be considered the chief areas:—Stourbridge, Birmingham, Tutbury, Knottingley, Barnsley, Leeds, London, and Tyneside.

For lighting-glass generally, the districts including London, Manchester, Glasgow, Stourbridge, and Birmingham are noteworthy, but the industry is carried on in many other towns.

For pressed-ware, Glasgow, Gateshead, Manchester, Warrington, and Sunderland should be mentioned. Ship- and lamp-lenses are made in the same areas.

The plate-glass industry is practically confined to the St. Helens and Birmingham areas. Sheet-glass (window-glass, stained glass, etc.), is made at St. Helens, Birmingham, and Oldbury, and staining is carried on at Edinburgh.

In the matter of the total amount of raw materials used and fuel consumed, the bottle-making branch of the industry is of course by far the most important. It would be laborious to enumerate the places at which bottles are made; the manufacture is ubiquitous, and only the chief localities can be mentioned. The South Yorkshire area is, of course, the district *par excellence* for this work. The bottle-industry of Tyneside has declined considerably. Medical bottles are made in the London, Yorkshire, Gateshead, Manchester, and St. Helens areas. Flint-glass bottles are produced in the same districts, and for ordinary pale and dark bottles the following localities also must be added: the districts of Sunderland, Edinburgh, and the Firth of Forth, Bristol, Newport (Mon.), Queenborough, Dublin, and Belfast.

Finally, as we should expect in a city which manufactures everything from a pin to a steam engine, "egg-boilers" and time-glasses, as well as the largest and most beautiful glass objects, have their birth in Birmingham.

From what has been stated above concerning the kinds of glass for which various British sands are suitable, and the location of both these sands and the corresponding glass-making areas, an idea may be obtained of the transport required. To assist the reader, the most important canals and navigable river-systems have been inserted on the Maps (Plates IX. & X.) together with the chief railway connexions. Transport by canal, sea, or rail, and the very variable freightage rates on different railways will, however, prevent comparison of the cost of moving any individual supply into any particular manufacturing area. Nevertheless, the maps are given for what they are worth.

CHAPTER XIII.

§ Economic Considerations.—General Remarks.

In the development of the national resources of raw materials for glass-making, questions of the cost of working, suitable treatment, and transport play a most important part.

The margin of profit upon sands is small. This and the fact that our large export coal-trade to the Continent enabled foreign sands to be brought back very cheaply as ballast have been mainly responsible for the small development of home resources of sands and allied rocks, and for the lack of investigation into them. The glass-manufacturer hitherto has not experimented to any great extent with British sands, and is thus not generally acquainted with their potentialities. Moreover, before 1914 it was by no means certain that the best British sands actually reached the manufacturer. Owing to lack of systematic working, want of proper treatment and careful transport, British materials sent to the glass-making areas have to overcome the prejudice which they previously caused. This state of affairs is now rapidly being remedied, since the cutting off of a considerable proportion of foreign supplies of sand, due to the shortage of labour and shipping caused by the war, has necessitated the systematic surveying and exploitation of British mineral resources.

When brought as ballast or packing for bottles, Belgian and Dutch sands could formerly be delivered in our East Coast estuaries at from 4*s*. to 5*s*. per ton. Fontainebleau sand was similarly delivered (although it was not usually brought as ballast) at 10*s*. per ton. These prices were doubled or trebled by the time the sand reached inland glass-making districts, the railway freights on sands being high. Even then the prices were below those of British sands, since the cost of production of the latter was, as a rule, greater.

The prices at which sands etc. can be supplied are, of course, liable to fluctuation according to the state of the labour market, cost of fuel, etc. The figures quoted in the foregoing chapters therefore vary within small limits.

Since the outbreak of war, partly owing to the greater demand for British materials and partly as a result of certain facilities having been granted which permit cheaper working, British sands are being delivered at a price which will enable them to compete successfully with foreign supplies. This improvement has been effected and a systematic development made possible by the high cost of foreign sands at the time of writing. Fontainebleau

sand costs from 20s. to 60s. per ton, and Belgian and Dutch sands 17s. to 23s. per ton, when procurable at all, according to the position of the glass-making area. Even when prices return to the normal level it will be possible for sand-merchants to exploit their deposits if the demand is sufficient and if railway and canal facilities are given. Some British sands have for many years been carried as ballast from one part of the coast to another.

High class glass-sands, like the sand from Fontainebleau, have frequently been used in this country in what might be termed a wasteful manner for common glass-manufacture. In certain maritime areas the sand can be obtained as cheaply as a less pure one, and is therefore used. In other areas, rather than have two different sands in use in the same glass-house, entailing possibility of confusion (which is perhaps unnecessarily feared), the manufacturer uses the same sand for crystal table-ware and also for commoner glass.

As a result of the importation of foreign sands, many British supplies which were formerly worked have been abandoned. Glass-sand appears to have fallen very considerably in price during the last fifty years, for, in 1858, Aylesbury sand fetched 25s. per ton at Aylesbury. In comparison with the present prices of British glass-sands given in the previous chapter, it may be stated that the average price in the United States of America is 4s. per ton.

Each of the economic factors will be considered in turn.

Workability.—In recommending sources of sand suitable for glass-making (or, for that matter, any other industry) due consideration must be given to the very important question of workability. Since the margin of profit on sands and gravels is low, attention must be paid to many factors other than those concerned with the actual properties of the sand. Of the latter, the high silica and low iron-content, low heavy-mineral percentage, absence of harmful minerals, the even grade (medium or fine sand), and possibly the shape, are the chief points to be considered. High content of alumina and potash are at times valuable.

In the field occurrence of the sand, due regard must be paid to the regularity of the deposit, the quantity available, the location with respect to supplies of fuel and markets, and to transporting routes, whether by road, rail, canal, or sea. The accessibility of the deposits—on hills, near bogs and marshes, on river-bottoms (from which they are dredged), or in sea-cliffs—as well as the conditions of quarrying (workable depth below ground-level, position of water-table, direction of drainage, thickness of overburden, etc.), and the state of the local labour market have to be considered.

Treatment.—The cost of washing sands is usually about 6d., or perhaps rather more, per ton. The additional handling and moving consequent upon washing, drying, or treating magnetically a sand or

crushed rock, raise the cost considerably. Little washing is done in England, and where it is carried on, ordinary draining and air-drying are generally considered sufficient. The question is, of course, one of cost; but washed deposits ought to be dried before being put on rail or on board ship, for carriage should not be paid upon water. Sands have the power of retaining a considerable quantity of water, and their hygroscopic nature should be clearly recognized. When crushing, washing, and drying are carried on, the proximity and price of fuel supplies and the available water-supply are important factors. If the crushing, screening, etc., of pure sandstones and quartzites ever becomes a paying proposition in this country, a considerable quantity of raw materials will be found to occur in the older rocks, especially in Scotland and Ireland. At present, for all but the best glass-ware, most of these are ruled out. If a rock which has to be crushed is to be worked successfully, it must be exceedingly good in chemical composition, and fairly accessible.

Such rocks are at times of value for the alumina or the alumina and potash, as well as the silica, which they contain. If they are very hard, subsequent electromagnetic treatment is necessary, after crushing, to free the sand from particles of steel, etc., derived from the crushers. The cost of electromagnetic separation is 6*d.* or more per ton, according to local conditions.

Where sandstones and quartzites are disintegrating under atmospheric conditions, working may be carried out profitably, for the crushing, washing, and drying are done by natural means for the exploiter, and the deposit often needs screening only. If such deposits or other glass-sands are situated at a suitable elevation and water-power is available, the use of monitors to wash down the sand may be found advantageous. Gravity will then assist in transport, and the washing may well improve the quality of the product, both as regards mechanical composition and iron-content.

The enormous glass-industry of the Middle Mississippi Basin is supplied by crushing the St. Peter's Sandstone, which crops out in the States of Minnesota, Wisconsin, Iowa, Illinois, Missouri, Arkansas, etc. It is blasted, crushed, screened, washed, and dried. The well-known Oriskany sandstone of West Virginia (Berkeley Springs, etc.) is similarly treated (see Chapter XI.). Certain pure quartzites are, it is said, now being crushed and treated in Sweden to provide the sand for the manufacture of the well-known laboratory glass. Before 1914, Fontainebleau and Lippe sands were imported for the purpose.

Transport.—Carriage by road is expensive, and aerial transit, even for short distances and when aided by gravity, does not always appear to be satisfactory, besides being frequently costly. Railway freights upon sand (as well as upon the finished article, glass) should be reduced so as to permit the transportation of English glass-sand over any distance. Glass-sands, being purer,

are unfortunately at present subject to a more expensive rate than ordinary sands. Canal-transport should replace rail-transport wherever possible in developing British sand-resources, and must be further revived and reorganized for this purpose, as too few of our deposits are situated near the sea or large rivers (see Plate IX.). There is urgent need for the improvement, repairing, and widening of canals. With a decrease in the cost of transport, it may well be that the sand-merchant will find it possible to treat and improve his sand (perhaps to dry as well as wash and screen it) before delivery, and thus more successfully compete with foreign supplies. Co-operation between users and producers ought to lead to increased demand, and therefore to more extensive and cheaper exploitation.

The levying of greater import duties upon foreign sands may not be desirable, but it may have to be considered. If British sands are to be exploited to any large extent, the question of the necessity for a revision of freights, leading to standardization and reduction is urgent. It should be noted that certain Continental supplies of glass-sand are larger, more regular and persistent, and in part purer than deposits in our own country.

Statistics.—The available figures relating to the imports and exports of sands are of the most meagre character. In the Home Office Returns of Minerals, etc. *, it is stated that the Production of Gravel and Sand in 1913 was 2,409,152 tons of value £184,818, and in 1914 was 2,498,872 tons of value £215,351. The value was therefore about 1*s.* 6*d.* to 1*s.* 8*d.* per ton. The production of sandstone in 1913 was 3,977,303 tons of value £1,143,431, and in 1914 was 3,464,528 tons of value £1,057,096. The value was therefore about 5*s.* 9*d.* to 6*s.* per ton. In 1915 the output of sand and gravel was 2,350,267 tons of value £213,373 (1*s.* 10*d.* per ton), and of sandstone, 2,520,856 tons of value £758,325 (6*s.* per ton). No separate figures exist to indicate even what proportion of the total was occupied by sand, much less to show what was the separate production of building-sands, glass-sands, moulding-sands, soap-making sands, filtration-sands, abrasive-sands, etc.

For the following figures dealing with imports and exports of sands, the writer is indebted to the Comptroller-General of the Department of Commercial Intelligence of the Board of Trade. The total value of the exports of Earth and Sand of British production during the five years 1911 to 1915 was as follows:—

1911	£38,884
1912	23,912
1913	23,470
1914	15,773
1915	10,655

* Home Office: Mines & Quarries General Report: Part III., Output for 1915 (1917), and previous issues.

STATEMENT showing the Imports and Re-exports of SAND into and from the United Kingdom in the years 1911–1915.

		Total Imports.	of which from :— Belgium.	France.	Total Re-exports.
1911	Tons	223,095	197,670	25,554	7
	£	85,322	68,623	16,377	15
1912	Tons	228,822	197,187	27,582	8
	£	89,338	68,712	18,399	27
1913 .. .	Tons	273,352	233,754	35,157	1
	£	103,095	79,085	20,724	2
1914	Tons	195,860	150,945	33,523	.
	£	80,643	54,165	19,173	..
1915	Tons	102,103	35,043	33,662	537
	£	65,433	20,239	24,815	741

With the exception of a little special moulding-sand and furnace-sand, this imported material may be taken to be sand for glass-making purposes. The figures tell their own story of war-conditions.

General Remarks.—As a result of the chemical investigation which has been going forward while this geological enquiry has been in hand, it has been found that a lower standard of purity than that hitherto admitted may be permissible in glass-sands. Owing to the paucity of chemists and works' laboratories in the glass-trade generally, little check has been kept upon other raw materials, and these have frequently been found to be impure. It should be possible to obtain the latter in a high degree of purity, and if any latitude is permitted, it should certainly be in the sand, where freedom from iron and casual impurities is more difficult to ensure than in manufactured chemical products. The sand has often been suspected, while the manganese dioxide, red lead, limestone, or even felspar, have been responsible for the iron. On the other hand, by varying the composition of the glass, less pure sands may be used to produce excellent ware, of water-whiteness and great brilliancy. The limit of iron oxide in sands for certain optical glasses may, according to Professor Sir Herbert Jackson, even reach 0·04 per cent.

The cost of chemical treatment of sand may also not be prohibitive when the manufacture of optical glass is under consideration.

While there are deposits in this country equal in quality to Fontainebleau sand, they do not appear to equal that deposit in extent and maintenance of sample. Our very pure and well-graded sands are of limited extent, but we possess large supplies of sand suitable for flint-glasses, soda-glasses, laboratory-ware, lamp-chimneys, globes, bottles, etc. Suitable sands for black and green bottle-work are common enough, and are widely distributed. The

price paid for sands for common glass in many British areas is far higher than it need be.

Good crystal ware has been made from Aylesbury sand, and the application of this and other sands to best glass-work is steadily growing. Selected samples might well be tried for certain optical glasses *. For such glass the variation in cost of sand is small compared with the considerable cost of production. It has been said that the whole world's trade in optical glass would not yield a stockbroker's profit. Before the war the production of optical glass probably did not amount to more than a few tons a year. The price of the sand is therefore not such an acute question, and a highly desirable sand will be obtained at any reasonable price, even where transport is expensive.

Early in this Memoir it was pointed out that sands suitable for glass-making (and therefore carrying a high percentage of silica, or silica and alumina) were of great value to the steel-founder for furnace-bottoms, soaking-pits, moulding-sands, silica-bricks, crucible-making, etc. We must note that the price paid for such sands by steel manufacturers and founders is usually well in advance of, and sometimes double as much as, that which the glass-maker is prepared to pay. Freedom from iron oxide or a very low percentage of it is not essential to the steel-maker; it is therefore desirable that the best silica-sands should, if possible, be retained for glass-making. Many deposits exist which are of great use as refractories, but are quite unsuitable for glass-making.

Glass-manufacturers have been very fortunate in being able to obtain from abroad large and constant supplies of their essential raw material, pure sand, at a comparatively low price. The constancy in grade and chemical composition has enabled them to go forward with very little alteration of batch, and with no apparent need for investigation and analysis. The future cannot be ignored. It must be understood that foreign deposits, in particular those of Fontainebleau, are not inexhaustible, nor is it likely that they will always arrive in this country so cheaply or so true to sample in consignment after consignment as they did before 1914. The output of Fontainebleau sand might at any time be restricted for domestic reasons, or a tariff might be put upon it. It therefore behoves glass-manufacturers to investigate the properties of their glass-sands and the questions of suitability or unsuitability of British supplies. More skilled chemists must be employed in the works to investigate not only the finished products and the necessary mixtures for special glasses, but also the chemical and mechanical composition of their raw materials, including sand. The discussion of the uses and nature of sands, and of the methods

* While this Memoir has been in the press, excellent optical glass has actually been manufactured from a number of British sands, many less pure than Aylesbury sand.

of study, together with the requirements of good glass-sands, have been expanded in this Memoir with the view of aiding glass-manufacturers to investigate sands for themselves. Chemical analysis is familiar to all. Mechanical analysis can be carried out with very little apparatus, which is also such as can generally be blown in the works. Mineral analysis indicates the presence or absence of certain objectionable minerals in glass-making, and will enable the manufacturer to determine, within certain limits, whether his successive consignments come from the same bed or quarry. The last method of work, for example, is sufficient to prove at the present time whether the consignments of sand, which may well vary slightly in chemical or mechanical constitution, are the same Belgian or Dutch sand as that hitherto obtained.

Our Colonial resources of sand, particularly with reference to moulding (or, perhaps, refractories generally) and glass-making, ought to be thoroughly investigated. If it becomes desirable that, for certain special glasses, such as the valuable and important optical glass, the Empire should become self-supporting, it is highly probable that sands of sufficient purity and of suitable grade will be found in the Colonies, and may be shipped home, possibly as ballast. Such sands occur, among other places, in India, British Guiana, South Africa, and Victoria. The pulps obtained by crushing quartz-rock for extracting gold are often very pure; they accumulate in large quantities, but the remoteness of their location possibly rules them out. A revival of interest has recently taken place in Indian glass-making. The Tertiary deposits of Northern India are of similar age and character to those of Western Europe, which contain such excellent glass-sands. India may, therefore, well be self-supporting in the matter of glass-ware, and, if desired, may provide the necessary pure sands for British optical glass-making. This is one case among many, but it serves to emphasize the desirability of further investigation and of closer union in industrial and scientific questions between the Colonies and the Mother country.

TABLE I.—BRITISH GLASS-SANDS: IRON-CONTENT.

With a few exceptions, complete analyses were not made of the sands mentioned below.

Percentage weights, as Fe_2O_3.

Page.			Page.		
	Pre-Cambrian:—			*Jurassic*.—	
81	§Muckish Mountain, Trench 1	·028	90	Brora	·12
81	,, ,, ,, 2	·022	65	§Huttons Ambo, unwashed	·13
81	,, ,, ,, 3	·009	65	,, ,, washed	·03
81	,, ,, Bulk sample	·02			
96	Westport, uncrushed	·04		*Wealden*:—	
96	,, crushed, No. 3	·04		Bexhill	·06
93	Port-a-cloy (*a*)	1·82	52	§Fairlight, old pit	·02
93	,, (*b*)	·09	52	,, church pit (bulk)	·02
93	,, (*c*)	·23	52	,, ,, ,, another	·023
			52	,, ,, ,, selected	·002
	Carboniferous:—		54	§Bulverhyth	·04
86	§Caldwell, washed and screened	·08	55	§Ashurstwood (*a*)	·01
91	§Cookstown, red sand	·04	55	,, (*b*)	·015
91	,, washed	·02			
92	Coolkeeragh, unwashed	·13		*Lower Greensand*:—	
92	,, washed	·075	58	§Leighton Buzzard, unwashed	·14
89	§Glenboig, N.B.	·27	58	,, ,, washed	·09
82	§Guiseley, uncrushed	·03	56	§Lynn (Boam), unwashed	·19
82	,, crushed	·09	56	,, ,, double washed	·04
..	Londonderry	·11	56	,, (Gay & Wilson)	·16
				Eocene:—	
115	Meldon rock, A	Fe_2O_3 ·03, FeO ·26	71	Fordingbridge, A	·03
			71	,, B	·02
115	,, ,, B	FeO ·15	69	Longdown, unwashed	·09
			69	,, washed	·06
83	§Mold, unwashed	·024			
83	,, washed	·020		*Doubtful age*:—	
115	Par china-stone, uncrushed	·08			
115	,, ,, crushed	·12	102	§Ribden	·38
	Permian:—			*Glacial*:—	
...	Pontefract, treated	·09	...	§Bawtry, unwashed	·71
			...	,, washed	·68
	Trias:—		64	Rainford, unwashed	·05
76	Alderley Edge	·12	64	,, washed	·03
127	Eaglescliffe, untreated	·20			
127	,, treated (coarse)	·03		*Shore-Sands*:—	
127	,, ,, (fine)	·048	77	Ardara, Maghera	·70
84	§Spital, unwashed	·06	...	Clonakilty	1·23
84	,, washed (another sample)	·09			
74	§Worksop, unwashed	·51	139	India, 21/186	·08
74	,, washed (anal. J.H.D.)	·19	135	,, K/624	·24

§ These sands are also of value for refractory purposes.

TABLE II.—CHEMICAL ANALYSES OF BRITISH GLASS-SANDS.

Percentage weights.

Page.		SiO_2.	Al_2O_3.	TiO_2.	Fe_2O_3.	CaO.	MgO.	K_2O.	Na_2O.	Loss on ignition.	Total, etc.
	Pre-Cambrian :—										
95	§Appin Quartzite (Argyllshire)	96·40	2·06	n. d.	0·07	0·20	0·11	1·03	0·10	0·27	100·24
96	§Holyhead Quartzite (Anglesey)	99·32	0·19	0·03	0·02	0·12	0·08	none	none	0·21	99·97
..	Inchnadamff Quartzite (Sutherlandshire)	98·44	0·95	0·03	0·04	0·05	none	0·49	none	0·24	100·24
81	§Muckish Mountain, 1916	99·37	0·36	n. d.	0·05	n. d.	n. d.	n. d.	n. d.	0·12	99·90
81	,, ,, bulk sample, 1917	99·55	0·17	n. d.	0·02	0·20	tr.	none	none	0·16	100·10
..	Twelve Pins (Connemara)	94·00	3·01	n. d.	0·11	0·30	0·22	1·53	tr.	0·49	99·66
96	Westport quartz, uncrushed	99·51	n. d.	n. d.	0·004	n. d.	n. d.	n. d.	n. d.	n. d.	99·51
96	,, ,, No. 3 sample	99·20	0·24	n. d.	0·04	0·09	tr.	n. d.	n. d.	0·23	99·80
93	Port-a-cloy (*c*)	80·48	11·57	n. d.	0·23	n. d.	n. d.	n. d.	n. d.	3·25	95·53
93	,, (*a*)	76·47	12·66	0·31	1·82	0·12	0·45	5·05	0·31	2·94	100·13
	Ordovician :—										
95	§Stiper Quartzite, Pontesbury (Salop)	96·47	2·24	n. d.	0·06	0·21	0·12	0·58	none	0·59	100·27
	Carboniferous :—										
90	Ballycastle	98·57	0·52	0·05	0·02	0·20	0·05	0·06	0·05	0·42	99·94
86	§Caldwell, N.B.	93·74	4·11	n. d.	0·04	0·27	0·12	0·46	0·03	1·37	100·14
87	,, ,, refractory sand	86·48	7·43	0·74	0·43	0·11	0·12	2·37	0·03	H_2O+ 2·04, H_2O- 0·20	Organic matter, 0·08; ZrO_2, P_2O_5, & Cl, none; BaO, 0·03. Total 100·06
91	§Cookstown	96·97	1·61	n. d.	0·04	0·20	0·11	0·15	0·03	0·72	99·83
92	Coolkeeragh	84·96	8·59	0·18	0·18	0·34	0·31	4·54	0·08	1·54	100·72
82	§Guiseley, uncrushed	98·93	0·60	n. d.	0·03	0·24	none	n. d.	n. d.	0·29	100·09
82	,, crushed, another sample ..	97·45	1·76	n. d.	0·09	0·13	tr.	n. d.	n. d.	0·78	100·21
87	§Kilwinning, N.B.	98·85	0·53	0·06	0·02	0·11	0·06	tr.	none	0·38	100·01
88	§Levenseat, N.B.	99·46	0·16	0·04	0·03	0·13	none	none	none	0·19	100·01
88	,, ,, another sample, unwashed	97·00	2·02	n. d.	0·20	0·14	none	n. d.	n. d	0·76	100·12
83	§Mold, washed	98·97	0·46	0·04	0·02	0·10	0·07	0·08	none	0·34	100·08
84	§Mow Cop	92·67	4·62	0·26	0·05	0·14	0·09	0·19	none	1·88	BaO, trace. Total 99·90

§ These sands are also of value for refractory purposes.

CHEMICAL ANALYSES OF BRITISH GLASS-SANDS (*cont.*).

Percentage weights.

Page.		SiO_2.	Al_2O_3.	TiO_2.	Fe_2O_3.	CaO.	MgO.	K_2O.	Na_2O.	Loss on ignition.	Total, etc.
	***Trias*:—**										
85	§Spital	94·60	2·99	n. d.	0·06	0·20	0·14	1·44	none	0·65	100·08
127	Eaglescliffe, treated	93·59	3·51	n. d.	0·03	0·16	0·14	0·94	0·83	0·66	99·86
	***Inferior Oolite*:—**										
68	Denford	98·19	1·23	n. d.	0·06	0·15	none	n. d.	n. d.	0·46	100·09
65	§Huttons Ambo, washed	99·04	0·84	n. d.	0·03	0·10	0·18	n. d.	n. d.	0·19	100·38
	***Kelloway Beds*:—**										
67	Burythorpe, Fox Cover pit	96·79	1·63	n. d.	0·22	n. d.	n. d.	n. d.	n. d.	0·60	99·24
67	Burythorpe Park, bore 1	96·70	1·49	0·35	0·07	0·12	0·07	0·84	0·08	0·56	100·28
67	" " " 7	97·73	1·41	n. d.	0·06	trace	trace	0·74	0·12	0·32	100·38
68	§South Cave	94·80	2·93	n. d.	0·13	0·14	trace	1·42	0·22	0·47	100·11
	***Wealden*:—**										
52	§Fairlight (Ashdown Sands)	99·47	0·24	n. d.	0·002	0·29	trace	none	none	0·20	100·202
55	§Ashurstwood (Tunbridge Wells Sands)	98·77	0·73	n. d.	0·01	0·14	trace	n. d.	n. d.	0·43	100·08
	***Lower Greensand*:—**										
51	§Aylesbury, best quality	99·80	0·32	n. d.	0·03	n. d.	n. d.	n. d.	n. d.	0·22	100·37
51	" washed	99·39	0·48	n. d.	0·02	n. d.	n. d.	n. d.	n. d.	0·13	100·02
51	" bulk sample	98·76	0·37	n. d.	0·03	0·17	0·10	0·04	none	0·33	99·80
62	§Aylesford	99·06	0·56	n. d.	0·04	0·17	trace	0·26	0·11	0·22	100·42
63	§Bearsted and Hollingbourne	99·25	0·31	n. d	0·04	0·09	none	none	none	0·31	100·00
59	Flitwick	98·30	0·87	n. d.	0·18	n. d.	n. d.	n. d.	n. d.	0·47	99·82
60	§Godstone	99·56	0·26	n. d.	0·06	n. d.	n. d.	n. d.	n. d.	0·24	100·12
58	§Leighton Buzzard (Arnold's pits) washed	99·05	0·23	n. d.	0·14	0·31	0·08	none	none	0·31	100·12
58	" " " unwashed.	99·59	0·25	n. d.	0·21	n. d.	n. d.	n. d.	n. d.	0·27	100·32
58	" " " a fine grade	96·77	1·77	n. d.	0·27	0·15	0·03	0·60	0·02	0·63	100·24
58	" " (Garside's pit)	99·58	0·27	n. d.	0·03	0·28	none	none	none	0·13	100·23
56	§Lynn (Boam's pits), best quality	99·23	0·59	n. d.	0·04	0·11	0·02	n. d.	n. d.	0·25	100·24
56	" " refractory sand	97·34	1·34	trace	0·19	0·09	trace	0·37	trace	0·76	100·09
61	§Reigate (Doods Rd. pit)	98·93	0·67	n. d.	0·02	trace	none	n. d.	n. d.	0·28	99·90
	***Eocene*:—**										
72	Alum Bay (Headon Hill Sands)	96·96	1·90	n. d.	0·11	0·34	trace	n. d.	n. d.	0·64	99·95
73	§Charlton (Thanet Beds)	95·21	2·43	n. d.	0·42	0·19	none	0·89	0·19	0·88	100·21

71	Fordingbridge (Bagshot Sands)	99·28	0·17	0·07	0·02	0·11	none	none	none	0·27	99·92
89	Longdown, " " ...	95·41	2·35	n. d.	0·09	0·26	0·18	1·33	trace	0·50	100·12
	? *Miocene* :—										
101	§Torrington...	96·20	1·67	0·78	0·07	0·18	none	0·29	0·44	0·55	99·78
	Doubtful age :—										
102	§Abergele ...	99·35	0·54	n. d.	0·04	n. d.	n. d.	n. d.	n. d.	0·36	100·29
102	§Brassington ...	90·40	6·56	n. d.	0·185	0·16	trace	n. d.	n. d.	2·48	99·78
102	§Newhaven ...	98·17	0·71	0·42	0·02	0·11	0·07	0·09	0·02	0·41	100·025
102	§Parsley Hay (High Peak)	74·54	18·04	n. d.	0·05	0·19	none	n. d.	n. d.	7·24	100·06
	Glacial :—										
64	Rainford, washed ...	96·59	1·72	n. d.	0·03	0·19	0·08	1·05	0·05	0·43	100·14
	Recent :—										
...	Belfast Lough	89·70	4·15	0·35	0·76	0·72	0·61	1·72	0·67	H_2O+ 0·71, H_2O- 0·34	BaO & ZrO_2, trace; P_2O_5, none; Cl, 0·03; CO_2, 0·22; MnO, 0·01; Organic matter, 0·11. Total 100·10
77	Jura, N.B., shore-sand	97·89	1·19	n. d.	0·07	0·18	0·08	n. d.	n. d.	0·42	99·88
77	Sandymount Strand (Dublin)	84·24	3·61	n. d.	0·47	4·65	0·46	n. d.	n. d.	4·81	98·24

Colonial Glass-Sands.

139	Dog-trap Gully, Victoria, Australia	97·20	1·46	n. d.	0·10	0·23	0·07	0·24	0·10	0·38	99·78
139	* Jubbulpore, India ...	98·95	0·39	0·06	0·02	0·11	none	0·08	0·02	0·36	99·99
139	† Sand from India K 623	97·53	1·02	0·09	0·04	0·13	0·13	0·38	0·24	0·35	Cl. trace. Total 99·91
139	" " " K 626	98·10	0·84	0·17	0·04	0·15	0·07	none	none	0·63	MnO, 0·03. Total 100·03
139	" " " K 630...	99·39	0·11	0·07	0·04	0·15	0·05	none	none	0·20	100·01

* The Jubbulpore sand is used in the Allahabad glass-works.

† The writer has recently received nineteen samples of Indian sands, sent by the Director of the Geological Survey of India, at the instance of the Indian Industrial Commission. The samples are being examined, and the analyses quoted are of the best samples.

TABLE III.—SUNDRY CHEMICAL ANALYSES OF ALUMINA- AND POTASH-BEARING ROCKS, ETC.

Percentage weights.

Page.		SiO_2.	Al_2O_3.	TiO_2.	Fe_2O_3.	CaO.	MgO.	K_2O.	NaO.	Loss on ignition.	Total, etc.
98	Bridgwater Brick	58·20	16·42	1·29	Fe_2O_3, 6·74; FeO, 0·13	7·37	3·02	3·65	0·93	H_2O, 2·50	P_2O_5, 0·07; CO_2, 0·13; MnO, 0·08. Total 100·53
99	Baked Clay (Nuttall's Works)	63·99	15·17	0·65	6·13	n. d.	n. d.	n. d.	n. d.	n. d.	85·94
106	Brandy Gill, granophyre	80·12	10·68	0·09	Fe_2O_3, 0·06; FeO, 0·49	1·01	0·63	1·42	3·44	H_2O+ 0·80; H_2O- 0·28	CO_2, 1·29; P_2O_5, tr.; MnO, 0·05; BaO, 0·01; ZrO_2, 0·03; S, 0·09. Total 100·40
106	Wicklow, felsite, H 5 ...	82·88	9·39	0·15	Fe_2O_3, 0·22; FeO, 0·56	0·09	0·20	1·83	3·98	H_2O+ 0·48; H_2O- 0·13	P_2O_5 & S, none; BaO & Cl, trace; ZrO_2, 0·02. Total 99·99
106	Tramore (Waterford), felsite, C1							7·43	0·76		
106	,, ,, ,, C 2	78·84	10·50	0·14	Fe_2O_3, 0·33; FeO, 0·26	0·20	0·07	8·65	0·41	H_2O+ 0·57; H_2O- 0·10	MnO, 0·02; BaO, 0·03; S, 0·23; Cl, trace; P_2O_5, none; Total 100·35 less O for S ·08 — 100·27

106	Tramore (Waterford), felsite, C 3 ...							[illegible]	[illegible]		
106	" " " C 4 ...							5·94	2·03		
106	" " " C 5 ..							7·71	1·12		
106	" " " C 6							8·87	0·95		
106	" " " C 8							8·12	0·10		
106	" " " C 9 ...							7·88	0·08		
106	" " " E							7·99	0·[illegible]		
106	" " " F ..							5·98	0·87		
...	Colcerrow (Cornwall), granite ..							6·91	2·38		
115	Meldon (Devon), aplite	71·07	16·79	0·06	0·27	0·87	0·05	3·83	4·92	1·87	Cl. trace 99·73
115	Par (Cornwall), china-stone	75·23	14·27	n. d.	0·08	1·64	0·20	4·35	2·81	1·44	100·02
100	Roche (Cornwall), "coarse micas" ..	48·18	36·14	0·15	0·98	0·13	0·28	2·12	0·23	11·93	100·14
	Glauconitic Sands:—										
117	Bramford (Suffolk), Thanet Sand .	60·61	9·73	0·70	Fe_2O_3, 9·67; FeO, 0·45	1·22	1·89	2·98	0·33	12·38	P_2O_5, 0·13. Total 100·09
117	" " " " another sample .							4·12	none		
117	Collin Glen (near Belfast), Greensand..	44·76	5·62	0·45	Fe_2O_3, 9·21; FeO, 2·05	14·56	2·20	4·40	0·09	H_2O+ 3·24; H_2O- 2·48	P_2O_5, 0·02; MnO, 0·07; CO_2, 10·64; Cl & BaO, trace. Total 99·79
118	Folkestone, Lower Greensand (*a*) ..							1·20	0·17		
118	" " " (*b*)							1·14	0·25		
118	Maiden Bradley (Wiltshire), Upper Greensand							1·28	none		
118	Sudbury (Suffolk), Thanet Sand .							3·19	0·08		

Table IV.—Chemical Analyses of Felspar-Bearing Rocks (Pegmatites).

Percentage weights.

Page.		SiO_2.	Al_2O_3.	TiO_2.	Fe_2O_3.	CaO.	BaO.	MgO.	K_2O.	Na_2O.	Loss on ignition.	Total, etc.	Calculated Mineral Composition.		
													Potash felspar.	Soda felspar.	Quartz, etc.
	England :—														
108	Kernick, Trevisco . .	63·65	20·24	none	0·22	1·20	none	0·18	8·12	4·76	1·30	99·67	48·12	40·33	11·17
..	Luxulyan	64·36	19·41	0·09	0·51	0·26	0·10	0·16	12·43	2·11	1·18	99·61	73·66	17·90	8·05
107	Tresayes, Roche . . .	64·21	19·66	none	0·18	0·35	none	0·07	12·35	2·79	0·73	100·34	73·18	23·67	3·49
108	Trelavour Downs	64·36	19·56	none	0·10	0·19	trace	0·03	13·07	2·35	0·53	100·19	77·45	19·94	2·80
	Scotland :—														
110	Durness	70·36	15·97	none	0·08	0·12	0·53	0·08	10·42	2·19	0·29	100·04	61·74	18·53	19·72
110	Laxford Bridge . .	71·53	15·33	trace	0·05	0·28	0·60	0·15	10·43	1·91	0·21	100·49	61·80	16·26	22·49
109	Overscaig	69·05	16·84	none	0·07	0·21	0·12	0·06	10·08	2·83	0·42	99·68	59·71	24·01	15·96
109	,, (Geological Survey analysis) .	72·94	14·26	0·06	0·21; FeO 0·22	0·23	0·25	0·08	7·42	3·49	H_2O— 0·05; H_2O+ 0·17	Li_2O, trace; P_2O_5, 0·49; MnO, 0·11; CO_2, 0·06; 100·04	43·96	29·61	24·09
	Ireland :—														
112	Belleek, Columbkille	70·96	15·53	none	0·27	0·28	0·16	0·07	10·95	1·55	0·48	100·25	64·90	13·15	22·20
113	,, Garvary Wood	70·47	16·63	0·06	1·05	0·49	0·01	0·37	5·91	3·71	1·55	100·25	35·02	31·48	33·75
111	,, Derryrona . . .	73·18	14·58	none	0·06	0·22	trace	0·08	10·48	1·52	0·27	100·39	62·10	12·89	25·40
111	,, Scardans Lower .	73·07	14·71	none	0·05	0·22	0·02	0·05	10·14	1·60	0·46	100·32	60·07	13·57	26·68
112	,, Larkhill	65·74	18·36	none	0·06	0·21	0·03	0·13	13·08	2·07	0·25	99·98	77·49	17·56	4·88
114	Belmullet Quarry (Co. Mayo).	71·86	15·37	trace	0·16	0·22	0·02	0·08	9·61	2·55	0·42	100·09	56·95	19·94	23·20
114	Derrylogan (Co. Donegal)								7·15	2·18			42·38	18·49	39·13
114	Doolough (Co. Mayo) . .	73·75	14·27	none	0·20	0·51	0·26	0·11	7·25	2·99	0·65	99·99	42·96	25·37	31·66
114	Erris Head (Co. Mayo) .	70·50	15·78	none	0·29	0·18	0·06	0·07	10·32	2·26	0·59	100·05	61·17	19·17	19·71
114	Gweebarra Ferry (Co. Donegal)	78·09	12·83	trace	0·39	1·28	trace	0·19	2·53	3·99	0·68	99·98	14·99	33·85	51·16
114	,, ,, Excavations (Co. Donegal)	..		..					8·48	2·01			50·26	17·05	32·69
	Scandinavia :—														
114	Belleek Pottery	65·60	19·05	none	0·02	0·26	none	trace	12·12	3·08	0·28	100·41	71·82	26·13	2·46
..	Wedgwood's Pottery, Etruria.	65·43	18·98	none	0·03	0·19	trace	0·06	12·60	2·68	0·29	100·26	74·69	22·73	2·84

TABLE V.—MECHANICAL ANALYSES OF BRITISH GLASS-SANDS.

Percentage weights. In these tables the grade-percentages down to 0·25 mm. have been obtained by sifting. It should be mentioned that 0·25 mm. screen has been found on measurement to be nearer 0·2 mm.

Page.	Sand.	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5 mm.	FS. >0·1 & <0·25 mm.	s. >0·01 & <0·1 mm.	c. <0·01 mm.	S. Total sand-grade: >0·1mm.	Colour.	Ignition.
	Pre-Cambrian:—									
81	§Muckish Mountain, Trench 1		2·5	72·8	19·9	3·6	1·8	95·2	flesh-coloured.	no change.
81	„ „ „ 2	2·0	14·7	73·9	7·9	0·5	1·0	98·5	white.	„
81	„ „ „ 2*a*		9·8	73·1	15·8	0·8	0·5	98·7	cream.	„
81	„ „ „ 3	2·5	13·6	75·4	7·5	1·0	0·0	99·0	pure white.	„
81	„ „ „ 4		0·3	36·7	58·3	3·2	1·5	95·3	cream.	„
96	Westport (Achill I.), 0				0·3	0·7	99·0	0·3	white.	„
96	„ „ 1			a few grains	3·5	1·8	94·7	3·5	„	„
96	„ „ 1 *a*			2·0	17·9	36·5	43·6	19·9	„	„
96	„ „ 2		0·2	9·0	53·5	23·5	13·8	62·7	„	„
96	„ „ 3		1·0	85·5	11·6	0·4	1·5	98·1	„	„
96	„ „ 4		54·9	42·9	0·5	0·2	1·5	98·3	„	„
93	Port-a-cloy (*a*)		2·6	55·6	29·8	8·1	3·8	88·0	grey.	greyer.
93	„ (*b*)			49·7	44·7	4·5	1·1	94·4	cream.	„
93	„ (*c*)			34·2	46·0	9·0	10·8	80·2	whitish.	„
93	„ (*d*)			31·3	57·4	8·8	2·5	88·7	„	„
	Carboniferous:—									
90	§Ballycastle		3·3	82·8	12·0	1·1	0·8	98·1	cream.	browner.
86	§Caldwell, N.B.		5·5	82·9	5·8	1·1	4·7	94·2	„	„
91	§Cookstown	1·8	9·7	80·6	4·2	0·3	3·4	96·3	„	greyer.
92	Coolkeeragh		7·1	75·9	7·5	3·0	6·5	90·5	pale brown.	darker.
89	§Glenboig, N.B.		11·3	82·6	4·3	0·5	1·3	98·2	brown.	„
87	§Kilwinning, N.B.	13·5	30·0	54·6	1·1	0·2	0·6	99·2	cream.	greyer.
88	§Levenseat, N.B.		3·7	88·5	6·0	0·2	1·6	98·2	„	darker.
115	Meldon	>2 mm.. 24·6 >1 mm., 18·5	10·1	20·2	12·5	8·2	5·9	85·9	grey.	greyer.
...	§Miners	17·5	31·3	50·1	0·2	0·2	0·7	99·1	white.	grey.
83	§Mold		9·2	78·1	10·5	0·9	1·3	97·8	whitish.	greyer.
84	§Mow Cop	13·3	13·5	50·0	11·2	2·2	9·8	88·0	yellow.	darker.
89	§Plean, N.B.	sifted to 1 mm.	7·8	80·6	5·8	1·4	4·4	94·2	pale grey.	„

§ These sands are also of value for refractory purposes.

Mechanical Analyses of British Glass-Sands (*continued*).

Percentage weights.

Page.	Sand.	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5 mm.	FS. >0·1 & <0·25 mm.	s. >0·01 & <0·1 mm.	c. <0·01 mm.	S. Total sand-grade: >0·1 mm.	Colour.	Ignition.
	Trias:—									
76	Alderley Edge (Keuper Sandstone)		2·4	76·9	17·2	1·6	1·9	96·5	pale brown.	greyer.
127	Eaglescliffe, 1 „ „		0·1	15·3	82·7	1·5	0·4	98·1	white.	no change.
127	„ 2*a* „ „				94·7	4·2	1·1	94·7	„	„
127	„ 2*b* „ „			73·5	25·7	0·5	0·3	99·2	„	
84	§Spital (Keuper Sandstone)	sifted to 1 mm.	3·1	83·4	9·7	0·7	3·1	96·2	pale brown.	browner.
74	§Worksop (Lower Bunter)	2·0	6·6	58·6	26·2	4·5	2·1	93·4	dirty white.	darker.
	Inferior Oolite:—									
68	Corby, Lr. white Estuar. sands			mica only 1·3	73·5	16·0	9·2	74·8	cream.	pinker.
68	Denford „ „ „			2·9	92·3	3·0	1·8	95·2	whitish.	„
65	§Huttons Ambo, Up. Est.		1·4	84·9	7·5	4·1	2·1	93·8	„	grey.
68	South Cave—Entrance to pit			4·7	83·0	3·3	9·0	87·7	whitish.	pale grey.
69	Tadmarton			80·7	12·5	2·0	3·8	93·2	grey.	red-brown.
	Kelloway Beds:—									
67	Burythorpe Roadside pit		...	36·0	63·1	0·8	0·1	99·1	browner.	rather greyer.
67	„ Fox Cover pit		few grains only	39·2	59·0	1·0	0·8	98·2	as Belgian sand.	slightly greyer.
67	„ Park, bore 1	..		48·5	50·8	0·6	0·1	99·3	grey.	darker.
67	„ „ „ 7			50·9	47·6	0·7	0·8	98·5	„	browner.
...	Leavening			49·3	48·4	0·5	1·8	97·7	pale brown.	darker.
68	§South Cave		..	8·3	90·2	0·7	0·8	98·5	pale grey.	greyer.
	Wealden:—									
55	§Ashurstwood (Tunbridge Wells Sand)		0·3	7·1	91·5	0·4	0·7	98·9	cream.	browner.
...	Bexhill (Ashdown Sands)		..	a few mica flakes only	84·7	13·7	1·6	84·7	pale grey.	greyer.
54	§Bulverhyth (Ashdown Sands)	...	0·8	77·9	20·3	0·5	0·5	99·0	white.	no change.
...	East Hoathly (Ashdown Sands)		..	23·8	69·7	5·8	0·7	93·5	pale brown.	redder.

52	§Fairlight (Ashdown Sands)			83·7	16·1	0·1	0·1	99·8	cream.	redder.
52	„ „ „ church pit		1·1	55·5	42·6	0·4	0·4	99·2	„	grey.
52	„ „ „ old pit		0·2	44·2	54·3	0·8	0·5	98·7	„	„
...	Tunbridge Wells			89·7	5·5	3·8	1·0	95·2	pale brown.	redder.
	Lower Greensand :—									
...	Ashford		...	83·1	15·7	0·5	0·7	98·8	yellow.	brown.
51	§Aylesbury Windmill pit		<0·1	70·3	28·7	0·7	0·3	99·0	almost white.	no change.
51	„ Arnold's pit (best)		0·3	85·1	14·5	0·1	0·0	99·9	„ „	„
51	„ as supplied (washed)		few grains only	78·3	15·0	5·8	0·9	93·3	fairly white.	no change.
62	§Aylesford		few grains only	83·7	16·0	0·3	0·0	99·7	cream.	redder.
63	§Bearsted and Hollingbourne			94·6	4·2	0·8	0·4	98·8	cream.	browner.
	Blackgang Chine, I. of W.		0·5	42·5	55·7	0·6	0·7	98·7	„	pinker.
59	Flitwick		0·7	83·5	14·6	0·5	0·7	98·8	grey.	darker.
60	§Godstone		0·6	73·0	25·7	0·2	0·5	99·3	almost white.	faint purplish pink.
58	§Leighton Buzzard (Garside's pit)	4·2	25·3	69·7	0·7	0·1	0·9	99·9	pale brown.	pinker.
58	„ „ (Harris's pit)	{ >2 mm., 0·8 >1 mm., 28·5 }	50·6	17·2	0·2	0·4	2·3	97·3	„ „	darker.
58	„ (Arnold's pits), unwashed	6·6	21·7	70·2	1·0	0·2	0·3	99·5	brown.	„
58	„ „ „ washed	6·1	6·4	85·7	0·1	1·0	0·7	98·3	pale brown.	„
58	„ „ „ a fine grade			28·6	68·0	2·2	1·2	96·6	white.	greyer.
56	§Lynn (Boam's pits), best white			94·8	4·9	0·2	0·1	99·7	as Belgian. grey-brown.	„
56	„ „ unwashed		0·5	95·1	2·7	0·8	0·9	98·3	grey.	darker.
56	„ „ double washed			90·8	8·7	0·2	0·3	99·5	„	slightly darker.
56	„ (Gay & Wilson's pit)			71·1	27·2	1·0	0·7	98·3	brown.	darker.
60	Oxted		12·4	86·3	0·9	0·1	0·3	99·6	rather browner.	redder.
61	§Reigate, Caves		4·7	84·9	6·5	0·4	3·5	96·1	cream.	„
61	„ Doods Road pit		2·7	79·0	14·5	1·8	2·0	96·2	almost white.	slightly darker.
61	„ Park Lane pit	0·3	2·3	88·4	7·9	0·4	0·7	98·9	cream.	redder.
61	Rogate		1·2	81·2	16·6	0·2	0·8	99·0	„	pink.
	Eocene :—									
72	Alum Bay, I. of Wight (Bagshot)			8·1	76·2	10·7	5·0	84·3	almost white.	slightly darker
72	„ „ (Headon Hill Sands)			3·8	84·0	9·7	2·5	87·8	„ „	„ „
73	Brockenhurst (Bagshot)		..	3·8	56·2	37·4	2·6	60·0	pale brown.	redder. „

MECHANICAL ANALYSES OF BRITISH GLASS-SANDS (*continued*).

Percentage weights.

Page.	Sand.	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5 mm.	FS. >0·1 & <0·25 mm.	s. >0·01 & <0·1 mm.		c. <0·01 mm.	S. Total sand-grade >0·1 mm.	Colour.	Ignition.
	Eocene (*cont*). :—										
..	Bromley (Blackheath Beds)			0·7	86·5	11·8		1·0	87·2	pale brown.	redder.
73	§Charlton (Thanet Beds)			16·2	79·6	3·1		1·1	95·8	pale yellow-brown.	darker.
73	East Wickham (Thanet)			3·0	76·6	18·6		1·8	79·6	,, ,,	,,
71	Fordingbridge (Bagshot Beds)			88 3	11·2	0·3		0·2	99·5	grey.	,,
69	Longdown, W. end (Bagshot)			8·9	84·6	3·8		2·7	93·5	pale brown.	,,
69	,, E. end ,,			5·9	91·2	1·5		1·4	97·1	,, ,,	,,
73	Lymington (Bagshot)			13·5	76·7	9·0		0·8	90·2	,, ,,	,,
73	St. George's Hill (Bagshot)			77·3	21·2	0·6		0·9	98·5	,, ,,	redder.
73	Stoborough (Bagshot)		14·9	80·7	1·7	2·1		0·6	97·3	,, ,,	,,
72	Whitecliff Bay, I. of Wight (Headon Hill Sands)			17·3	60·2	17·7		4·8	77·5	almost white.	slightly darker.
	Doubtful age :—										
104	§Abergele (Denbighshire)	2·6	8·6	77·7	8·8	2·3		0·0	97·7	white.	no change.
104	§Talargoch (Flintshire)	28·6	4·3	16 3	25·3	18·5		7·0	74·5	,,	,,
97	Ynyslas (Cardiganshire)	>2 mm., 8 0; >1 mm., 6·7	4·4	16·7	23·2	15·1		25·9	59·0	,,	,,
						>0·05 & <0·1.	>0·01 & <0·05.				
102	§Brassington (Derbyshire)		2·1	68·2	14·5	0·7	5·0	9·5	84·8	cream.	greyer.
102	§Carsington ,,		2·0	63·7	11·0	0·8	4·1	18·4	76·7	yellow.	brown.
102	§High Peak ,,		0·2	20·8	29·0	1·1	22·6	26·3	50·0	white.	no change
102	§Longcliffe ,,		2·2	58·6	23·7	0·7	5·2	9·6	84·5	cream	,,
102	§Newhaven ,,		0·2	49·9	30·4	1·0	10·9	7·6	80·5	,,	,,
102	§Rhes y cae (Flintshire)		0·9	72·4	21·4	1·1	2·1	2·1	94·7	,,	pinker
102	§Ribden (Staffs), 1		4·6	43·6	23·8	0·6	10·5	16·9	72·0	pale brown.	darker.
102	,, ,, 2		0·3	12·4	15·9	1·6	18·4	51·4	23·6	,, ,,	,,

	Glacial:—									
...	Scunthorpe (Lincs) ...		4·0	88·4	5·6	0·6	1·4	98·0	brown.	darker.
64	Rainford (Lancs), washed		1·3	84·5	13·1	0·2	0·9	98·9		no change.
	Shore- and Blown-Sands:—									
17	Aberdeen ...		2·0	91·2	3·3	2·9	0·6	96·5	medium brown.	much darker.
77	Ardara, Maghera		few shell frag.	98·3	1·3	0·3	0·1	99·6	yellow brown.	darker.
77	„ Sandfields (Co. Donegal)		0·4	83·6	15·8	0·2		99·8	pale brown.	„
77	Ballycastle (Co. Antrim) ...	3·1	16·1	78·4	1·4	0·5	0·5	99·0	brown.	dark brown
...	Ballyphetrish, Tiree ...		0·4	64·3	34·3	0·3	0·7	99·0	grey.	blacker.
...	Bamburgh (Northumberland)		few small shell frag.	94·8	4·7	0·5	0·0	99·5	pale brown.	darker brown.
	Blyth (Northumberland)		1·3	96·6	0·7	0·2	1·2	98·6	darkish brown.	darker.
77	Camas, Eigg, N.B.			98·0	0·8	0·5	0·7	98·8	whitish.	greyer.
77	Clonakilty (Co. Cork)		shelly flakes	75·8	23·5	0·4	0·3	99·3	grey.	blacker.
77	Coalisland, Washing Bay, L. Neagh..	4·5	22·6	71·2	0·2	0·3	1·2	98·5	brown.	darker.
	Culbin (Nairn) ...			76·1	22·2	0·8	0·9	98·3	„	slight change.
77	Curracloe, Rosslare (Wexford)			89·2	9·6	0·4	0·8	98·8	as Lynn.	redder.
77	Eigg, N.B.		2·9	94·8	0·2	1·6	0·5	97·9	mottled.	slightly pinker.
	Hartlepool ..		0·2	96·6	0·9	1·1	1·2	97·7	medium brown.	darker.
77	Jura, N.B.			95·8	4·1	0·1	0·0	99·9	whitish.	grey.
	Laggas Bay, Islay		shell frag.	28·1	71·2	0·6	0·1	99·3	pale grey.	darker.
77	Laig Bay, Eigg		0·3	53·2	45·0	0·5	1·0	98·5	grey.	redder.
	Macrihanish Bay		shell frag.	69·5	29·7	0·2	0·6	99·2	brown.	blacker.
..	Maghera Green			75·0	15·7	8·0	1·3	90·7	nearly white.	redder.
.	Montrose		0·4	96·4	2·5	0·2	0·5	99·3	brown.	darker.
..	Millisle (Co. Down)		0·1	19·3	79·5	0·2	0·9	98·9	„	„
..	Portrush (Co. Antrim)		0·9	97·8	0·5	0·2	0·6	99·2	„	„
.	St. Ives (Cornwall)		shell frag. 10·2	88·8	0·2	0·4	0·4	99·2	pale brown mottled.	whiter and blacker.
77	Sandymount Strand (Dublin)		much mica	31·1	64·9	1·7	1·6	96·7	brown.	darker.
77	Silver Strand (Wicklow)		0·7	92·1	6·4	0·9	0·6	98·5	as Leighton.	redder.
77	Sutton (Dublin) ...	1·5	14·0	82·7	1·5	0·1	0·2	99·7	brown.	darker.
139	Dog-trap Gully, Victoria, Australia..		0·6	13·8	61·2	11·7 17·5	5·2	75·6	white.	grey.
139	Jubbulpore, India ...		few grs.	91·1	8·4	0·1	0·4	99·5	cream.	pale brown
139	India, K 626 ...	0·5	11·5	65·4	19·8	1·4	1·4	97·2	grey.	darker.
139	„ K 630 ...		9·9	70·7	17·7	0·5	1·2	98·3	white.	pinker.

Table VI.—Chemical Analyses of European Glass-Sands.

Percentage weights.

Page.	Locality.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	Loss on ignition.		
130	§Lippe, best quality	99·88	0·18	n. d.	n. d.	0·21	Total 100·27 per cent.	Separate determination Fe_2O_3, 0·02 per cent.
130	do. second do.	99·73	0·20	n. d.	n. d.	0·23	,, 100·16 ,,	Separate determination Fe_2O_3, 0·03 per cent. [E. Spencer.
39	§Fontainebleau, Barnsley Glass Works	99·80	0·13	0·006	trace	0·18	,, 100·116 ,,	
39	do. Crown Glass Works, Derby	99·67	0·19	0·002	0·14	0·18	,, 100·182 ,,	MgO, none.
132	§Belgian, Barnsley Glass Works	99·38	0·30	0·02	n. d.	0·23	,, 99·93 ,,	
133	§Dutch, Knottingley Glass Works	99·23	0·50	0·02	n. d.	0·22	,, 99·97 ,,	
133	do. Edinburgh & Leith Glass Works	99·63	0·35	0·03	0·08	0·19	,, 100·28 ,,	MgO, a trace.

TABLE VII.—MECHANICAL ANALYSES OF EUROPEAN GLASS-SANDS.

Page.	Sand.	VCS. > 1mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5 mm.	FS. >0·1 & <0·25 mm.	s. >0·01 & <0·1 mm.	c. <0·01 mm.	S. Total sand-grade: <0·1 & <2 mm.	Colour.	Ignition.
39	§Fontainebleau—Barnsley Glass Works		<0·1	70·6	26·6	2·8	0·0	97·2	white.	no change
39	,, Edinburgh & Leith Glass Works			70·3	28·3	0·6	0·8	98·6	,,	,,
39	,, Crown Glass Works, Derby		0·5	85·3	12·7	1·1	0·4	98·5		,,
132	§Belgian—Barnsley Works		<0·1	99·3	0·3	0·4	0·0	99·6	almost white.	slightly pinker.
132	,, Knottingley ,,		9·6	83·3	5·9	1·2	0·0	98·8	slightly grey.	,, ,,
132	,, Sheffield ,,	0·7	6·5	91·0	1·4	0·4	0·0	99·6	pink.	slightly redder.
132	,, Manchester ,,		1·1	93·3	4·8	0·4	0·4	99·2	pale pink.	no change.
133	§Dutch—Knottingley ,,	One grain	0·7	68·0	30·8	0·5	0·0	99·5	slightly grey.	? greyer.
133	,, York ,,		0·4	93·5	4·8	1·3	0·0	98·7	slightly browner than last.	redder.
133	,, Derby ,,			95·3	4·2	0·3	0·2	99·5	white.	no change.
133	,, Edinburgh ,,		0·4	94·4	5·1	0·1	0·0	99·9	,,	,,
130	§Lippe, best			78·6	19·9	0·4	1·1 *	98·5	,,	,,
130	,, 2nd quality		10·2	85·8	1·4	1·0	1·6 *	97·4	,,	,,

* Hygroscopic water included

TABLE VIII.—ANALYSES OF DANISH GLASS-SANDS *.

Percentage weights. (Chemical details also added.)

Diameter in mm.

	>1 mm.	>0·5 & <1·0	>0·2 & <0·5	>0·1 & <0·2	>·05 & <0·1	>·01 & <0·05	<·01 mm.	Silica.	Iron oxide.
Svendborg, Tertiary Sand	0·2	9·0	53·2	34·6		3·0		97·5	0·12
Fænø			1·2	39·2	52·9	4·8	1·9	89·2	0·48
Vejle Fjord, Hvidbjerg	0·9	9·9	41·2	45·7		2·3		95·9	0·18
„ „ Tyrsbaek	1·1	11·6	53·2	31·2		2·9		93·4	0·22
Grejs Mølle	1·1	6·8	37·4	50·7		4·0		94·6	0·18
Grejs Dal, Tertiary Sand	>2 mm., 5·0 31·3	47·3	15·4	1·0 (<0·2 mm.)				99·1	0·08
Vejle Dal	0·5	31·8	65·6	2·1 (<0·2 mm.)				98·9	0·14
Stilling		0·1	21·7	75·9		2·3		97·5	0·17
With these are quoted for comparison :—									
German Sand		0·5	46·1	52·5		0·9		99·8	0·07
Belgian „		1·6	80·8	17·2		6·4		98·4	0·17

[From the above table it does not appear that Denmark is too well supplied with suitable glass-sands of her own.]

* Dan. Geol. Undersøg. ser. 2, No. 16: N. Steenberg, "Undersøgelser over Nogle danske Sandsorters Anvendelighed til Rudeglas og simplere Hvidglas."

TABLE IX. A.—ANALYSES OF AMERICAN GLASS-SANDS*.

Sieve Tests. Approximate percentage weights. Chemical Analyses.

Page.		Over 20.	Passes mesh.				SiO_2.	Al_2O_3.	Volatile matter.	Fe_2O_3.	CaO.	MgO.	Total.
			20	40	60	100							
137	Berkeley Springs, W. Va.		100	98	25	1							
.	Crystal City, Mo. (Pittsburg Plate Glass Co.).		·100	55	20	1	98·90	·20	·25	·002	·54	·20	100·092
...	Klondike, Mo.	Small lumps.	100	90	1	1	99·97			·03			100·00
135	Ottawa, Ill.		100	100	92	25	99·45	{ & Fe_2O_3 0·3 }			·13	trace.	99·88
..	Utica, Ill.	A few grains.	99 +	45	11	3	99·576	·283		·0903	·0197	·002	99·971

TABLE IX. B.—ADDITIONAL CHEMICAL ANALYSES OF AMERICAN GLASS-SANDS.

(By Dr. H. F. HARWOOD and Mr. A. A. ELDRIDGE.)

Percentage weights.

Page.	Sand.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Loss on ignition.	Total.
135	Ottawa Silica Co., Ottawa, Ill.	99·48	0·16	0·02	0·11	0·05	0·13	99·95
136	Wedron Silica Co., Ottawa, Ill.	99·58	0·12	0·02	0·13	tr.	0·17	100·02
137	Berkeley Sand Co., Berkeley Springs, W. Va.	99·65	0·11	0·02	0·12	tr.	0·23	100·13
138	Juniata Sand Co., Baltimore, Md.	99·33	0·16	0·02	0·15	0·11	0·20	99·97
136	Berkshire Sand Co., Cheshire, Mass.	99·00	0·30	0·03	0·15	none	0·21	99·69
138	Tavern Rock Sand Co., St. Louis	99·03	0·23	0·02	0·21	0·05	0·35	99·89

* Bull. 285, United States Geological Survey, 1906.

TABLE IX. C.—ADDITIONAL MECHANICAL ANALYSES OF AMERICAN GLASS-SANDS.

(By P. G. H. BOSWELL.)

Percentage weights.

Page.	Sand.	VCS. >1 mm.	CS. >0·5 & <1 mm.	MS. >0·25 & <0·5 mm.	FS. >0·1 & <0·25 mm.	s. >0·01 & <0·1 mm.	c. <0·01 mm.	S. Total sand-grade >0·1 mm.	Colour.	Ignition.
135	Ottawa Silica Co., Ottawa, Ill.		21·6	76·1	1·3	0·3	0·7	99·0	white.	slightly greyer.
136	Wedron Silica Co., Ottawa, Ill.		6·1	88·4	5·1	0·2	0·2	99·6	,,	no change.
137	Berkeley Springs, W. Va.		1·5	97·1	0·8	0·2	0·4	99·4	,,	,,
138	Juniata Sand Co., Baltimore, Md.	1·6	11·2	85·7	0·4	0·1	1·0	98·9	,,	,,
136	Berkshire Sand Co., Cheshire, Mass.	·	·	76·6	21·3	0·3	1·8	97·9	,,	,,
138	Tavern Rock Sand Co., St. Louis	·	2·7	90·1	6·1	0·5	0·6	98·9	,,	grey.

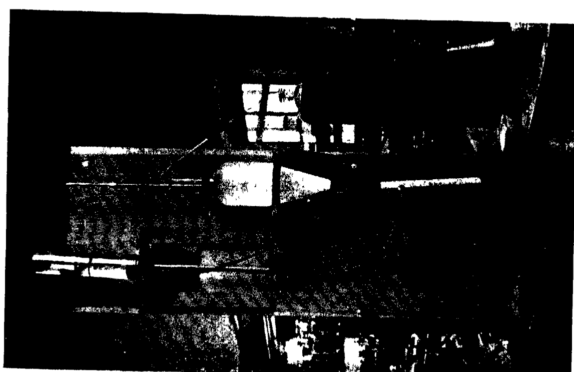


Fig 1.—Crook's Elutriator.

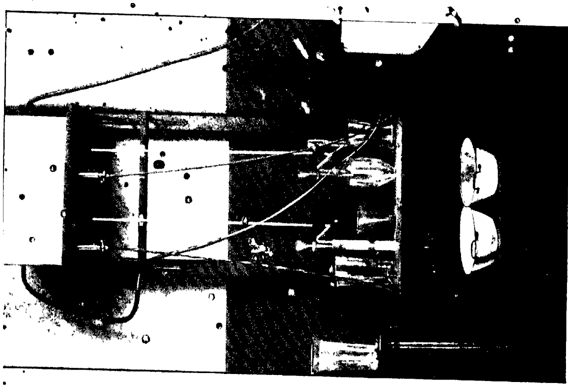


Fig. 2.—Stadler's modification of the Schoene Elutriator.

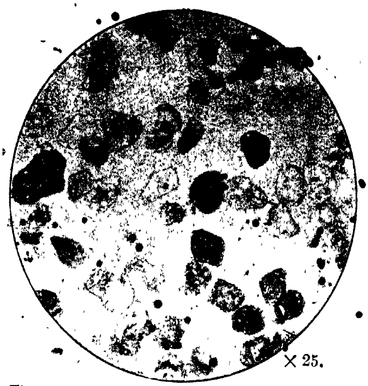


Fig. 1.—Quartz (faint and clear) and felspar (turbid) in a good glass-sand.

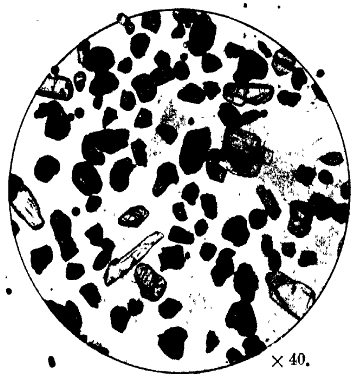


Fig. 2.—Heavy mineral residue from a British glass-sand: kyanite, staurolite, tourmaline, ilmenite, etc.

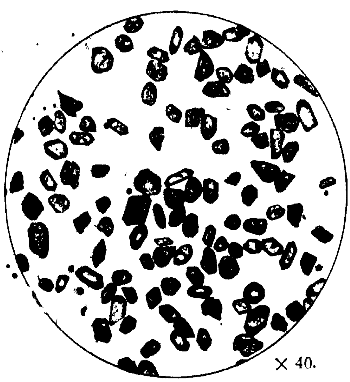


Fig. 3.—Zircon and Rutile: harmful minerals in glass-sands.

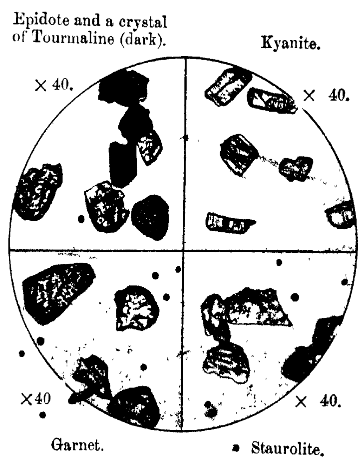


Fig 4.—Heavy minerals from Sands.

Photomicrographs of Minerals from Sands (transmitted light).

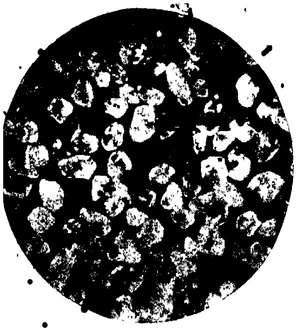


Fig. 1.—Fontainebleau Sand.

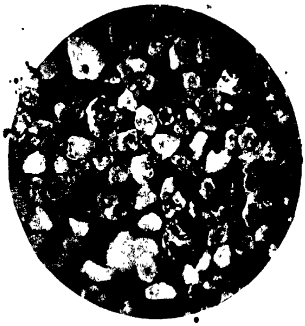


Fig. 2.—Lippe Sand.

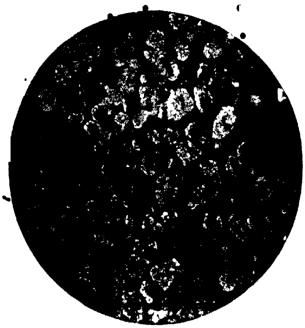


Fig. 3.—Aylesbury Sand.

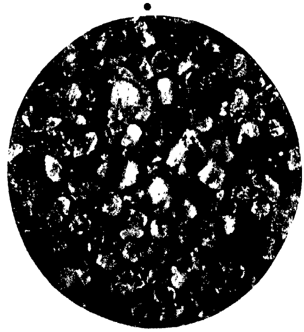


Fig. 4.—Godstone Sand.

Fig. 5.—Burythorpe Sand.

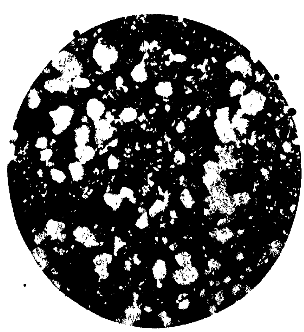


Fig. 6.—Crushed rock: Guiseley.

Photomicrographs of Glass-Sands (reflected light).

[All figures magnified 20 diameters.]

Fig. 1.—Huttons Ambo Sand, before being washed.

Fig. 2.—Huttons Ambo Sand, after being washed.

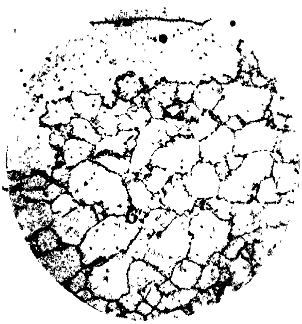


Fig. 3.—Muckish Mountain Quartzite; ordinary light.

Fig. 4.—Muckish Mountain Quartzite; crossed nicols. Same field as Fig. 3.

Fig. 5.—Crushed Vein-Quartz, Achill Island (Quality 3).

Fig. 6.—Sand from King's Lynn.

Photomicrographs of Glass-Sands (reflected light).

[All figures magnified 21 diameters.]

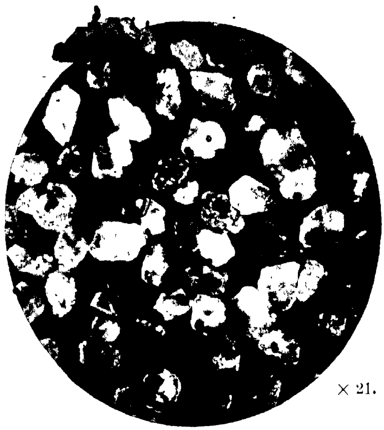


Fig. 1.—Sand from Berkeley Springs, West Virginia, U.S A.

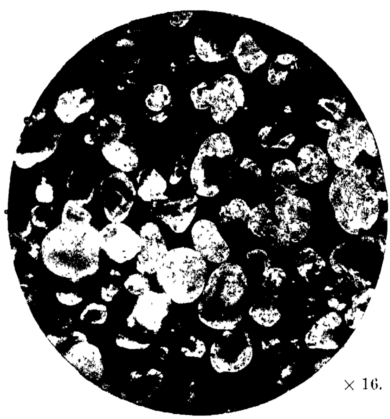
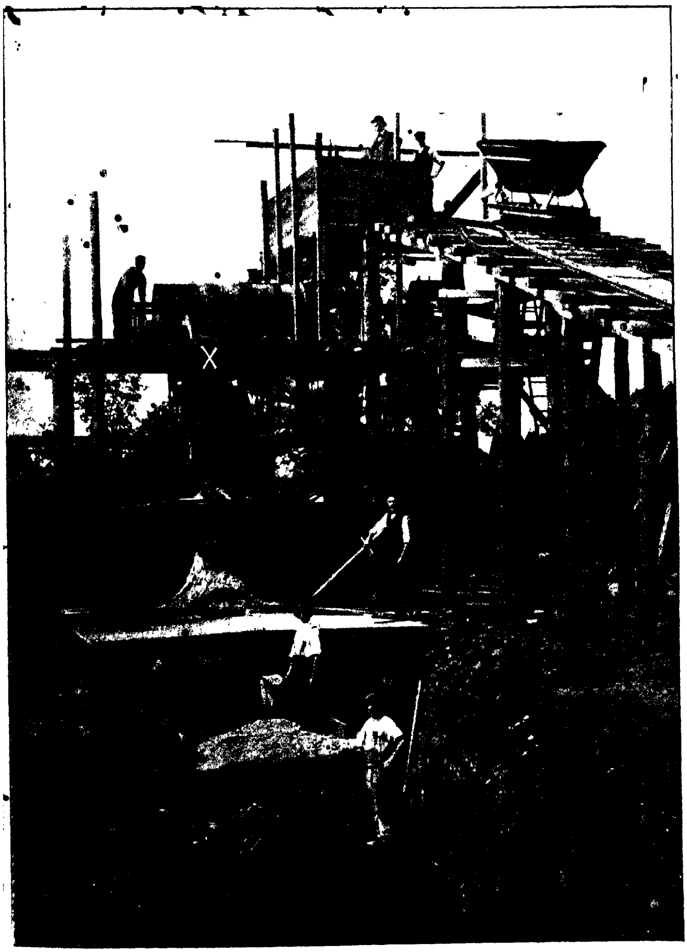


Fig. 2.—Sand from Ottawa, Illinois (Wedron Silica Company), U.S.A.

Photomicrographs of American Glass-Sands (reflected light)

Sand-pits near King's Lynn (worked by Messrs. Joseph Boam Ltd., for glass-making and refractory sands)

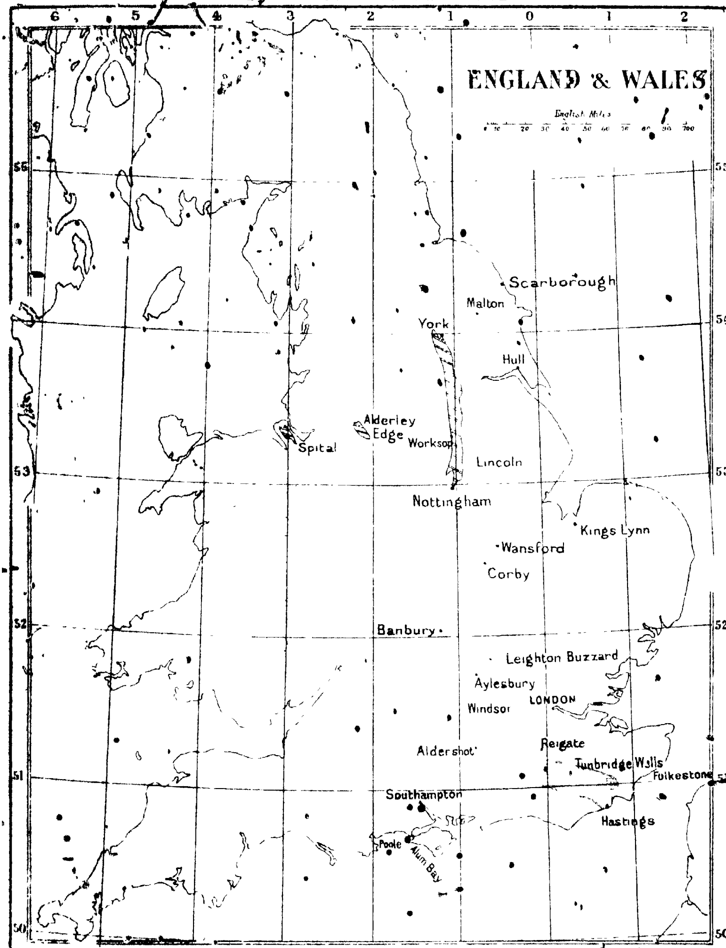


Rikof's Machine for the Washing of Sands

(The draining-cone shown in Fig. 13, p. 123, is partly obscured by the staging and is marked by a white cross.)

SKETCH-MAP SHOWING THE OUTCROPS OF THE GEOLOGICAL FORMATIONS IN WHICH GLASS-SANDS OCCUR, AND ALONG WHICH THE EXTENSION OF SUPPLIES MAY BE EXPECTED.

By Professor P. G. H. BOSWELL



Bagshot Beds, etc — Oolite Sands

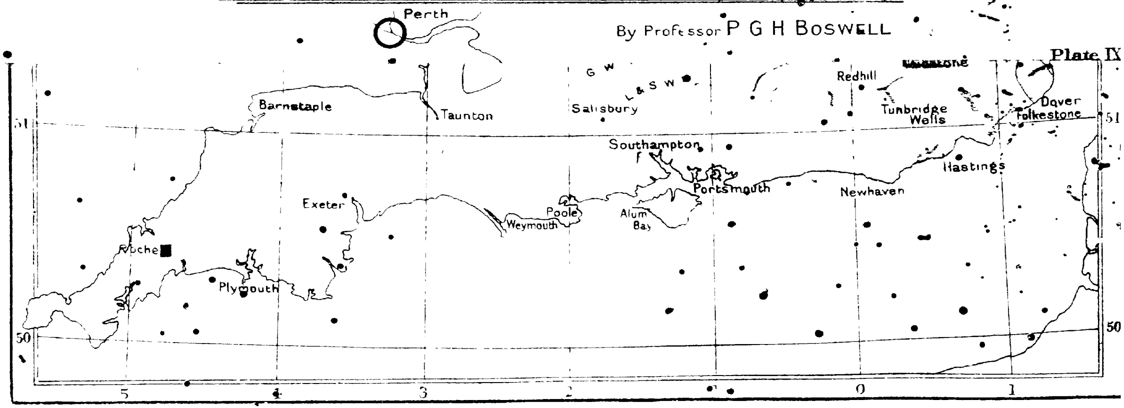
Lower Greensand — Triassic Sands

Hastings Beds — Sands for common bottle-glass are not included

Plate IX

SKETCH-MAP SHOWING THE LOCATION OF THE CHIEF BRITISH RESOURCES OF GLASS-SANDS IN RELATION TO THE GLASS-MAKING AREAS, COALFIELDS, RAILWAYS, AND INTERNAL WATERWAYS.

By Professor P G H BOSWELL



Glass-making areas

Coalfields

Glass-sand producing areas

Felspar (Roche etc.)

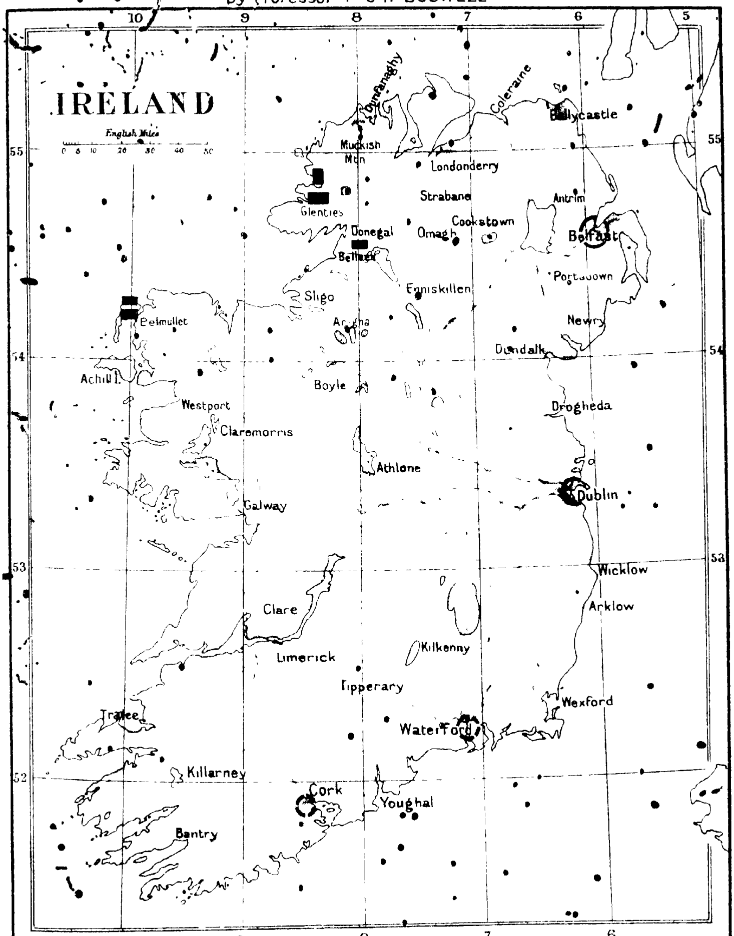
Railways in red Waterways & Canals in blue

The depth of colour in the glass-making areas yields an indication of the character of the glass made, the greatest depth of colour representing the commonest form of glass-ware. In the same way, the sand-producing areas are tinted in accordance with the sand produced, the palest colour marking the highest quality material

Plate X.

SKETCH-MAP SHOWING THE LOCATION OF THE CHIEF IRISH RESOURCES OF GLASS-SANDS IN RELATION TO THE GLASS-MAKING AREAS, COALFIELDS, RAILWAYS, AND INTERNAL WATERWAYS.

By Professor P G H BOSWELL



Glass-making areas

Coal Fields

Glass-sand producing areas

Potash-Felspar deposits

Railways in red

Canals & Waterways in blue

The depth of colour in the glass-making areas yields an indication of the character of the glass made, the greatest depth of colour representing the commonest form of glass-ware. In the same way, the sand-producing are tinted in accordance with the sand produced the palest colour marking the highest quality material

N B Glass was formerly made at Cork, Waterford, Ballycastle & other place Belfast & Dublin are now the only seats of the industry

W & C GRAHAM LTD LITHOS LONDON E C

INDEX.

Note.—Descriptions of particular Glass-Sands, etc. occur on pages marked in black figures.

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